Some Assembly Required: STEM Skills and Canada's Economic Productivity

The Expert Panel on STEM Skills for the Future

Council of Canadian Academies
Conseil des académies canadiennes

Science Advice in the Public Interest

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The Expert Panel on STEM Skills for the Future

THE COUNCIL OF CANADIAN ACADEMIES
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Library and Archives Canada Cataloguing in Publication

Some assembly required : STEM skills and Canada's economic productivity / the Expert Panel on STEM Skills for the Future.

Includes bibliographical references.

Electronic monograph in PDF format.

ISBN 978-1-926522-09-8 (pdf)

1. Economic development – Effect of education on – Canada. 2. Education – Economic aspects – Canada. 3. Knowledge economy – Canada. 4. Skilled labor – Canada. 5. Knowledge workers – Training of – Canada. 6. Canada – Economic conditions. I. Council of Canadian Academies. Expert Panel on STEM Skills for the Future, author

HD75.7.S64 2015 338.971 C2015-902258-4

This report can be cited as: Council of Canadian Academies, 2015. *Some Assembly Required: STEM Skills and Canada's Economic Productivity*. Ottawa (ON): The Expert Panel on STEM Skills for the Future, Council of Canadian Academies.

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Printed in Ottawa, Canada

Council of Canadian Academies
Conseil des académies canadiennes

Canada This assessment was made possible with the support of the Government of Canada.

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Message from the Chair

Canada has one of the most highly trained workforces in the world. The skills and abilities of Canadians have played a key part in ensuring that Canada has one of the highest standards of living in the world. Maintaining and developing Canada's strength in this regard is a central pillar of our future prosperity.

However, many new challenges are on the horizon — or already upon us. They include the rapid pace of technological change, an aging population, environmental concerns associated with increased resource extraction, and rapid growth of developing economies with large numbers of capable students. In this evolving global context, Canada must ensure that its workforce has the right balance of skills to take advantage of opportunities and be prepared to adapt to change.

An array of skills and assets are important, including those related to the arts and humanities, mathematics, social sciences, and natural and life sciences. We were asked to examine a particular set of skills: science, technology, engineering and mathematics (STEM) skills. STEM skills have been advanced as central to innovation and productivity growth, which are in turn necessary for improving standards of living. While the general reasons behind this logic are clear, the Panel had difficulty finding direct and robust evidence that STEM skills are unique in this regard. However, productivity growth is also about working smarter. The fundamental skills required for STEM literacy, such as problem solving, technological proficiency, and numeracy, represent essential components of working smarter. They are the building blocks of more advanced and specialized STEM skills, and they remain useful regardless of whether or not individuals choose STEM careers. Indeed, we found that these skills open doors to a range of education and employment options, and are thus vital for all Canadians.

After 18 months of study, we are convinced that high-quality investments in STEM skills — in both early education and in more advanced training — are critical to Canada's prosperity. Beyond preparing students and the labour force for a range of future possibilities, these investments appear to be one of several components required to improve Canada's poor innovation and productivity record.

To my colleagues on the Panel: thank you for your collaboration and dedication to this topic. Together, we thank Employment and Social Development Canada for sponsoring this study, and the staff at the Council of Canadian Academies for ably supporting us through the assessment process. We also appreciate the input of the 11 external reviewers who volunteered their time to critique an earlier version of this report.

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Acknowledgements

Over the course of its deliberations, the Panel sought input and assistance from many organizations and individuals who provided valuable evidence, information, and insights to be used in the development of the report. Special thanks go to the following: Alexander Danco, Jason Pearman, and Hamoon Ekhtiari, three exceptional young entrepreneurs who took the time to address and discuss their views about STEM and innovation and productivity with the Panel. Thanks also to Kristyn Frank, Marc Frenette, John Zhao, Darcy Hango, and Grant Schellenberg of Statistics Canada, who helped access valuable data and develop a classification of STEM fields; Matthew Calver of the Centre for the Study of Living Standards; Erwin Gomez Gomez, Senior Economist at Employment and Social Development Canada; and also the Canadian Mathematics Education Study Group.

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 **William R. Pulleyblank**, Professor of Operations Research, Department of Mathematical Sciences, US Military Academy (West Point, NY). 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 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 Professor Pulleyblank for his diligent contribution as Report Review Monitor.

Executive Summary

It is generally understood that skills make critical contributions to Canada's prosperity. However, there is uncertainty about precisely which skills are needed to thrive in tomorrow's economy, how skills directly contribute to innovation and productivity, whether some skills are more connected to these goals than others, and whether there is an optimal combination of skills that fosters growth. Many skills are required to advance human knowledge and social and economic development. However, in a complex and uncertain global economy, science, technology, engineering, and mathematics (STEM) skills are in the spotlight, as countries aim to maximize their economic competitiveness and productivity. As a result, governments, policy-makers, educators, and business leaders are particularly concerned about how well equipped Canada is with the STEM skills needed to fulfil labour market demands and promote innovation.

To gain the information required to make optimal investments in STEM skills, education, training, and labour force development in Canada, Employment and Social Development Canada asked the Council of Canadian Academies (the Council) the following question:

How well is Canada prepared to meet future skill requirements in science, technology, engineering and mathematics (STEM)?

Additional direction was provided through four sub-questions:

- *What role do STEM skills play in supporting and fostering innovation, productivity, and growth?*
- *What is the extent and nature of the global market for STEM skills and how does it interact with the Canadian market?*
- *How is labour market demand for STEM skills likely to evolve in the future? Which STEM skills are likely to be most in demand?*
- *What is known about the relative importance of different factors affecting Canada's supply of STEM skills, especially through the Canadian learning system and international migration?*

To address the charge, the Council appointed a multidisciplinary expert panel (the Panel) with a range of experience, expertise, and leadership in areas relevant to the charge, including economics, human resources, university and college administration, business, and STEM professions. In preparing its report, the Panel drew from two main sources of evidence: a comprehensive literature review and a new analysis of educational and occupational data on STEM skills. The Panel's findings represent its collective judgment based on its review of the best available evidence.

SUMMARY STATEMENT

Overall the Panel found no evidence of a current imbalance between the demand for and supply of STEM skills at the national labour market level. It also found insufficient direct evidence on the exact nature and impact of STEM skills on innovation and productivity growth. These findings suggest that the source of Canada's productivity problem is not a shortage of advanced STEM skills. Short-term, localized imbalances may exist, but the Panel emphasized the importance of focusing on long-term economic outcomes. Long-term projections on the need for specialized skills are highly difficult to undertake, especially considering rapid and inevitable changes in technology, economy, and society. As a result, it was not possible to definitively determine the skills and knowledge required for the jobs of the future.

However, it is clear that STEM skills are central to a variety of education and job opportunities. They provide individuals with options in uncertain labour markets. While maintaining Canada's advanced STEM skills capacity is important, investments in STEM literacy are crucial for developing a skilled society that is prepared to respond to an uncertain future. Increasing the quality and level of fundamental skills for STEM among all learners at the preschool, primary, and secondary education levels represents a strategic, long-term approach towards this goal. Such investments may also help to improve Canada's levels of innovation and productivity.

MAIN FINDINGS

It is not possible to definitively determine what skills and knowledge will be required for the jobs of the future. Proactive, long-term strategies to keep a range of economic options open include investments in building fundamental STEM skills while maintaining Canada's capacity for producing advanced STEM skills.

Long-term labour market demands are difficult to predict. A range of external forces influence the economy, including constant changes in technology and the increased capacity for automation. These forces can profoundly alter the nature of work. Nonetheless, STEM skills are central to a variety of education and job options. They equip individuals with essential tools that are required to adjust to change, which is a benefit considering future labour market uncertainties. Thus, long-term sustained investments in fundamental skills for STEM literacy in Canada represent a sensible response to growing uncertainty about the future of technology, the changing nature of work, and expected demands for skills. At the level of advanced STEM skills development, dedicated assets remain important for basic research.

To build this capacity and maximize Canada's potential for innovation, evidence points to the value of early childhood interventions to strengthen fundamental skills.

Results from standardized tests demonstrate that Canadian youth perform relatively well in science and mathematics-related domains. However, there remains significant room for improvement to increase the level of fundamental skills among all learners, as well as to grow the talent pool of top performers. High-quality interventions, in pre-primary education through to secondary school, are a significant factor in both of these endeavours. While there are many types of fundamental skills, STEM education provides a rich environment for developing some of them, including mathematics, computational facility, reasoning, and problem solving. These skills form the basis for more advanced STEM skills. As a result, fundamental skills for STEM are important for all Canadians, regardless of occupation. Beyond preparing students for a range of future possibilities, the Panel emphasized the urgency of the opportunity to invest in fundamental STEM skill building, suggesting that early investments may be one of a suite of components required to reverse Canada's poor innovation record.

There is no evidence of a current imbalance of advanced STEM skills nationally.

Canada appears to have a well-functioning labour market, where individuals are choosing fields of study and occupations based on factors such as market signals and personal preferences. This conclusion is based on a number of indicators, including employment and unemployment data, wages, and STEM education and occupation matching. Although smaller-scale mismatches by industry and region may exist, they are difficult to assess with available data. For example, compared with other provinces, earnings in Alberta are generally higher and have increased faster for STEM *and* non-STEM graduates, suggesting growing demand for skills and difficulty finding an adequate supply of educated workers in general. In other words, these signals are not unique to STEM graduates. Such a tight labour market is consistent with a fast-growing economy, rather than a shortage of particular skills.

Long-term economic outcomes matter.

While short-term, localized imbalances may be challenging, the Panel agreed that focusing on long-term economic outcomes is important. The Panel cautions that a focus on narrowly specialized STEM skills development to meet short-term labour market requirements may have little relevance for meeting long-term skill requirements. Short-term labour requirements in certain industries may quickly shift (e.g., the dotcom bust). New technologies are also creating industries and occupations that previously did not exist. Under normal market conditions, investing heavily in specialized training has significant risks for individuals and society: changes in demand for niche skills over time may result in obsolete or undervalued skills, and deep investments in one area come at the cost of not investing in other skills. Although dedicated assets are important for basic research, as well as development of new innovations, targeted labour market interventions to increase the number of STEM-skilled workers should not be required in a well-functioning, self-regulating economy.

STEM skills are necessary but not sufficient for innovation and productivity growth.

While the theoretical reasons for a link between STEM skills and innovation are clear, there is currently limited evidence on the specific contribution of advanced STEM skills to productivity growth, or the magnitude of these effects. The only clear evidence of the impact of STEM on innovation and productivity comes from a few preliminary studies. These suggest that STEM-skilled immigrants have a patenting advantage and regionally generate significant and positive wage increases for non-STEM, university-educated Canadian workers.

Other evidence suggests that more assets than STEM skills alone are required for productivity growth. First, there are many types of innovation, and not all of them depend on STEM skills. Complementary skills, such as communication, teamwork, and leadership, are also important in and of themselves, as well as to maximize the impact of STEM skills. Second, wages are one indicator of labour productivity. At first glance, STEM graduates appear to command higher wages than their non-STEM counterparts. A closer look reveals enough variation (by gender, level of education, immigration status, and STEM field) to call the accuracy of the commonly cited “STEM wage premium” into question. Third, since evidence on a current imbalance of STEM skills nationally is lacking, the Panel agreed that the source of Canada’s productivity problem is not a shortage of specialized STEM skills. As documented in other Council reports, demand-side issues cannot be solved with supply-side solutions.

In the Panel's view, the balance of evidence on the impact of STEM skills on innovation suggests that they generate meaningful benefits, leading to their judgment that STEM skills represent an important but not sufficient condition for innovation, productivity, and economic growth.

Support for under-represented populations in STEM is important for broadening Canada's STEM skill supply.

Canada is currently missing out on an important supply of skilled talent. Increasing the STEM participation of under-represented populations, including women and Aboriginal peoples, is an important strategy for diversifying the supply of STEM-skilled individuals. Just 29.6% of individuals with a post-secondary STEM credential and 26.9% of those employed in a STEM-intensive occupation in Canada are women. Increasing high school completion rates and post-secondary attainment among Aboriginal populations remains important. The implications of these serious disparities are costly for society, the economy, science, and innovation. By attracting individuals with diverse perspectives, experiences, and ideas, a wider talent pool can reveal deeper assets.

STEM skills are global skills.

STEM skills are globally transferable. In contrast to concerns throughout the 1990s about brain drain, data indicate that the emigration of STEM-skilled Canadians is more than offset by STEM-skilled immigrants, through a process known as *brain circulation*. Though immigrants account for 21% of Canada's population, they are a major source of STEM skills, representing around 50% of all STEM degree-holders in Canada at the bachelor's level and above. However, immigrants can experience difficulties connecting with the Canadian labour market, as demonstrated by their higher unemployment rates and lower employment rates compared with workers born in Canada. These outcomes have negative implications for individuals and Canada as a whole.

Beyond facilitating the presence of individuals with new knowledge and skills through immigration, bidirectional flows of skilled labour increase international connections: networks can accelerate the globalization of labour markets and open new opportunities for trade, investment, and entrepreneurship. Canada can draw on the global pool for highly advanced and specialized technical experts when the domestic capacity for niche STEM skills does not meet demand. However, it is less optimal to draw on temporary international labour to meet demand for skills in broad occupational categories. It may diminish the incentive for firms to train and develop employees' skill sets, as well as discourage individuals from investing in their own skills development. The Panel concluded that the long-term benefits of immigration are more important than the short-term goal of access to temporary labour.

Developing a flexible labour force requires collective, coordinated action to facilitate education, training, and mobility.

Flexibility in a range of education and training systems, including universities, colleges, polytechnics, employer-based training, and government programs, is required to help equip the next generation of learners with the STEM skills that they need as workers, and as members of society. Collaboration and coordination among post-secondary institutions, government, industry, and community organizations in Canada are important to enable a range of options, skills, and ongoing learning opportunities for individuals.

STEM SKILLS FOR THE FUTURE

The global economy is experiencing accelerated transitions. Major advances in information and communication technologies, nanotechnology, and genomics are changing businesses, society, and lives. An aging population and a shrinking labour force are driving demographic shifts in Canada. Declining growth in industrialized economies (including in Canada's major trading partner, the United States) and the emergence of new markets are shifting the concentration of export opportunities and import competition. The increasing global demand for energy is driving major environmental challenges. Against the backdrop of unstable energy prices, governments and enterprises are being challenged to become innovation leaders. At the same time, Canada is still striving to improve its poor productivity record. In many ways, these challenges and opportunities are linked to science and technology. In some cases, these links are clearer than in others. In the Panel's view, STEM skills are necessary for many types of innovation, as well as productivity and growth, but they are not sufficient on their own. Other skills such as leadership, creativity, adaptability, and entrepreneurial ability may be required to maximize the impact of STEM skills. Further, the Panel did not find evidence of a current imbalance in advanced STEM skills nationally, suggesting that the source of Canada's productivity problem is not a shortage of advanced STEM skills.

This finding does not diminish the critical importance of STEM skills to Canada and Canadians. STEM benefits society in many ways, from breakthrough drugs to safe structures, more efficient and sustainable forms of transportation, convenient apps, and innovative forms of workplace organization. Maintaining

Canada's capacity for producing advanced STEM skills, while finding new ways to foster demand for these skills through business innovation, remains essential for sustaining and improving our quality of life.

Given the inherent uncertainty of the future, one of the most proactive and strategic ways to be prepared in the long term is to ensure that Canadians have a strong base of fundamental skills. The fundamental skills that enable STEM literacy are prerequisites for a variety of education and career pathways. Such skills will equip individuals and the economy with the flexibility to take advantage of a number of opportunities, and increase the range of options available. Investments at the pre-primary through to secondary school levels are important to develop a STEM-literate society with strong fundamental skills. This action may be an important step towards improving Canada's poor innovation record.

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1 Introduction

From the industrial through the ongoing computing and communication revolutions, science and technology have improved the quality of life in industrialized societies and enriched our understanding of the world around us. We have benefitted from new products and services ranging from pharmaceuticals to computers, the capacity to grow more food and access more minerals and energy, and the ability to move faster and further than ever before. These improvements are largely the result of innovation — new products or processes — based on scientific knowledge, which is generated and applied by people skilled in science, technology, engineering, and mathematics (STEM). STEM skills cover a wide range of knowledge and skill types, from the technical training needed to operate sophisticated equipment, to world-leading research in physics or biotechnology, all contributing to a prosperous society. High-level STEM skills are important to advancing the frontiers of scientific knowledge, but so is having a broader STEM-literate population. The adoption of new technologies is often not possible without STEM-literate individuals with complementary skills who can turn ideas into products and services, and put them to use. Hence, improving the quantity and quality of all types of STEM skills can be important in increasing economic productivity of Canada's labour force and fostering long-term growth of living standards.

Scientific advances and technological innovations raise living standards by increasing productivity (economic output per unit of labour and capital input). Advances in technology allow workers to produce more in less time using fewer inputs of capital and resources. STEM skills help raise productivity over the long term by contributing to technological progress. People with STEM skills are needed to create scientific advances; to apply these advances to develop technologically improved products, equipment, and processes; and, most importantly, to get the most out of new technologically sophisticated equipment and processes. Although there are many types of innovation that can increase productivity, long-term productivity growth seems to rely ultimately on scientific and technological progress. Having the appropriate level of STEM skills and STEM literacy in the labour force may therefore be necessary (but not necessarily sufficient) for technological innovation in the long term, although the relationship between available skills and innovation is highly complex. Innovation is a non-linear and dynamic process that occurs within a complex ecosystem of actors, with firms as the central agents of innovation (see CCA, 2013c, 2013a).

Increasing the quality or quantity of workers with STEM skills, however, will not automatically translate into increased innovation in the Canadian economy. Other creative and commercial skills are also required. Compared with other countries, Canada's lacklustre productivity growth has been attributed to low levels of innovation in the business sector despite a strong and productive academic research sector (CCA, 2013c). Consequently, a greater level and supply of STEM skills will only translate into higher living standards in Canada if demand for these skills exists in the business sector, where they can be put to use in the economy.

Four "megatrends" signal a fundamental change in the global economy, and suggest that STEM skills will become increasingly important to Canada's future productivity growth (CCA, 2013c). First, like many countries, Canada's population is aging, leading to slower growth in the labour force, which makes increasing productivity all the more urgent to maintain living standards. Second, slower labour force and demand growth in the United States, combined with more rapid growth of a skilled labour force and demand in many emerging market economies, presents new challenges for Canadian firms, governments, and labour. Third, technological innovation and STEM skills can help mitigate and address environmental concerns arising from increased global exploitation of resources, especially energy. Finally, the rate of adoption of new technology seems to be accelerating, leading to revolutions in fields such as information and communication technologies (ICT), genomics, and nanotechnology. Although the exact implications of these revolutions are impossible to predict, to remain competitive Canadian firms across all sectors will need to be able to both innovate and adapt. STEM literacy will also provide more options for Canadians of all walks of life in a world of increasing technological change.

Although STEM and complementary skills are both important for scientific discovery, innovation, and productivity, the exact nature of the relationships and the role of STEM skills remain unclear. Several other countries, such as the United States, United Kingdom, and Australia, have studied the importance of STEM skills, and developed strategies for fostering and using them to greatest effect. In the context of Canada's lagging productivity growth, and the global megatrends mentioned above, Canada must urgently assess how prepared it is to meet future needs for STEM skills.

1.1 THE CHARGE TO THE PANEL

In 2013, the Minister of Human Resources and Skills Development Canada (now Employment and Social Development Canada, ESDC) asked the Council of Canadian Academies (the Council) to investigate the extent to which Canada is prepared to meet future demand for STEM skills in the labour force. Specifically, the Council was charged with answering the following assessment questions:

> *How well is Canada prepared to meet future skill requirements in science, technology, engineering and mathematics (STEM)?*
>
> - *What role do STEM skills play in supporting and fostering innovation, productivity, and growth?*
> - *What is the extent and nature of the global market for STEM skills and how does it interact with the Canadian market?*
> - *How is labour market demand for STEM skills likely to evolve in the future? Which STEM skills are likely to be most in demand?*
> - *What is known about the relative importance of different factors affecting Canada's supply of STEM skills, especially through the Canadian learning system and international migration?*

In response, the Council convened an 11-member multidisciplinary expert panel (the Panel) with diverse backgrounds and areas of expertise. Its members included economists, business leaders, human resource professionals, university and college administrators, and STEM professionals in engineering, biology, chemistry, and mathematics.

To ensure a full understanding of the charge, the Panel first met with representatives from ESDC to discuss the scope of the assessment. The topic of STEM skills is broad and touches on many aspects of education, training, and employment. To ensure the required breadth and depth of analysis, the Panel resolved that the assessment would:

- focus on the evolution of skill demands over the medium to long term, rather than assess short-term skill shortages or gaps, with the aim of examining how labour market demands for skills are evolving over longer time periods and the factors driving the changes;

- consider investment in STEM skills relative to investment in other types of skills, assessing the importance and role of different skill sets and the trade-offs involved in making education and training choices, at the individual and societal levels;
- recognize the role of provincial governments in education, immigration, and skills development and consider policy implications that extend beyond the federal jurisdiction;
- assess potential barriers to the development of STEM skills throughout the formal education system, including the Kindergarten to Grade 12 system; and
- consider the role of STEM skills relative to complementary skill sets (i.e., business skills, people skills, creativity, the ability to work in a team).

The Panel also identified topics that were largely out of scope. In particular, the assessment is *not* intended to provide a comprehensive review of pedagogical strategies related to STEM skills or issues related to curriculum design in STEM fields at any level of study. Although these critical issues merit further study, this assessment focuses primarily on assessing trends in skill demands in the Canadian labour market and the overall balance of the supply and demand for these skills.

1.2 DEFINING STEM SKILLS AND STEM FIELDS

Although internationally recognized standard definitions of innovation and related activities exist, with guidelines for measurement (OECD/Eurostat, 2005), there are many definitions of STEM used by organizations in different countries (Carnevale *et al.*, 2011; UKCES, 2011; Gonzalez & Kuenzi, 2012; Bosworth *et al.*, 2013; Office of the Chief Scientist, 2013). The “STEM” acronym was first used by the U.S. National Science Foundation in the early 21st century (Duggar, 2010), though it was essentially a rebranding of previous terms used since at least the 1990s (Donahoe, 2013). STEM has been used in various contexts to describe skills, academic disciplines, fields of education, study, or work. Each of these could contribute to innovation, productivity, and growth in different ways. For example, STEM (and other) workers apply skills acquired through a mix of formal education, professional training, and experience. Not all workers in a STEM occupation have a post-secondary credential in a STEM field, and not all STEM graduates work in a STEM occupation. Education in a STEM discipline is important, but it is only one source of high-level STEM skills or knowledge. Nonetheless, it is often used as a proxy measure for STEM competencies (Carnevale *et al.*, 2011).

STEM can be defined conceptually in terms of characteristic practices and approaches to knowledge that are distinct from other disciplines (Moon & Singer, 2012; Office of the Chief Scientist, 2013). Reliance on scientific methods, hypothesis testing, and computation are frequently associated with STEM, as fields of education and as occupations (Carnevale *et al.*, 2011; Office of the Chief Scientist, 2013). Carnevale *et al.* (2011) define STEM in terms of cognitive (knowledge, skills, and abilities) and non-cognitive (work values and interests) competencies associated with STEM occupations, noting that some of these may also be relevant to other occupations, to a lesser degree.

The Panel defined *STEM skills* as the set of core knowledge, skills, and capacities typically used or acquired in STEM occupations and/or acquired in STEM fields of study and programs. In this context, *skills* are understood to include what labour economists might refer to as competencies, knowledge, skills, and abilities.

The Panel distinguished between fundamental skills for STEM and more advanced levels of STEM skills, which are described in Section 1.2.1. The Panel also adopted a classification of STEM fields of study, developed by Statistics Canada, which is described in Section 1.2.2. The two definitions are somewhat related, but reflect different aspects of defining *STEM skills*. Skill types that are primarily conceptual can be difficult to measure for individuals and populations, whereas data on fields and levels of education are more readily available for analysis.

1.2.1 Types of STEM Skills

For the purpose of the assessment, the Panel distinguished between three main types of STEM skills, each with its distinct market and implications for policy responses.

Fundamental skills for STEM include reasoning, mathematics, and computational facility (numeracy), as well as capacity for critical thinking and problem solving, and the ability to apply these skills in technology-rich environments. They are important for nearly all Canadians, regardless of occupation, and can be learned at an early age. Together, they contribute to STEM literacy. Consumers require basic mathematical skills to manage personal finances prudently, prepare taxes, or arrange a schedule. Home maintenance requires some degree of spatial orientation skills, and some understanding of technology is necessary for optimal use of personal technologies. STEM literacy also allows citizens to make more informed decisions, and to appreciate and make appropriate use of new technologies as they become available. More importantly, evidence indicates that beginning from a young age, these fundamental skills form the building blocks for higher-level skills of all types, including those associated with non-STEM fields (see Sections 5.1 and 5.3). These include practical STEM skills, used by tradespeople and technologists, for example, and advanced STEM skills (e.g., novel scientific research and development (R&D) of new products).

Practical STEM skills include knowledge of established scientific principles and how to apply them to specific tasks or occupational roles. Some examples include the ability to solve algebraic problems, perform complex calculations, and understand and apply relationships based on basic physics, chemistry, or biology (this is not an exhaustive list). The capacity to modify existing technology and adapt it to a novel task or problem would also be considered a practical STEM skill, such as computer programming, or principles of technical design. Practical STEM skills build on fundamental skills and complement advanced STEM skills. The development of new technologies or products can benefit from practical STEM skills — such as for manufacturing and testing prototypes, or identifying problems that can be solved with existing technology — but such activities also require advanced STEM skills to generate fundamentally new ideas and designs. Firms need individuals with practical STEM skills to understand and adopt new technologies, or combine available technologies in ways that meet their needs. Practical STEM skills are associated with trades, apprenticeships, and education in a STEM field at the diploma or certificate level (one- to three-year programs). They can be acquired in less time than advanced STEM skills, and can also be more directly linked to short-term needs of employers. Nevertheless, practical STEM skills can also be an important part of other fields outside specialized STEM areas, at all levels (see Section 1.2.2). For example, although architecture is not considered a core STEM field, it still requires the practical application of engineering principles, technical design, and other practical STEM skills.

Advanced STEM skills include familiarity with scientific methods, conceptual design, as well as specialized STEM discipline-specific training and knowledge of disciplinary concepts (e.g., an understanding of atomic particles, molecules, or living cells). They allow someone to engage in discovery or applied research that expands our understanding of the physical world, or to develop fundamentally new technologies. Advanced STEM skills are important for creating and developing new ideas — and the frontier technologies that embody them — that are central to long-term productivity and economic growth. Firms need individuals with deep expertise in STEM to develop new innovations, perform specialized analyses and research, and understand and adopt new production technologies in ways that meet their needs. Advanced STEM skills and knowledge are associated with education at the undergraduate level and above (four years or more) in a STEM field, with high-level research at the doctoral level requiring an additional four or more years of advanced education. Practical STEM skills may also be learned or applied in these programs, although their focus is generally on advanced STEM skills.

1.2.2 STEM Fields

Science, technology, engineering, and mathematics may appear to be a short list of fields at first glance. However, this general definition leaves room for interpretation, with certain fields included in some definitions, but not others, particularly when it comes to "science."

While different definitions of STEM fields are used in other countries, the Panel chose to adopt Statistics Canada's STEM fields of education (StatCan, 2013b). This STEM definition "includes only those fields which advance the frontiers of science, technology, engineering, and mathematics knowledge" (John Zhao, personal communication, May 29 2014), and thus contribute to innovation and competitiveness through knowledge generation in core STEM areas. These are the fields considered in analyses throughout the report, unless otherwise noted (see StatCan, 2013b for full details):[1]

- **Science:** includes core fields of scientific inquiry, such as physics, chemistry, biology, and related fields that apply principles from these fields to the study of specific phenomena, such as environment, food, or materials. This group also includes medical sciences, but not regulated or practical health care instructional programs.
- **Technology:** includes programs that focus on the application of scientific and engineering principles to the development of new processes and technology for the manufacture of new and better products.
- **Engineering:** includes programs that prepare individuals to apply mathematical and scientific principles to the solution of practical problems, and technical skills to support related projects.
- **Mathematics and Computer Sciences:** includes pure (discovery-based) and applied mathematics and statistics, as well as sub-fields of various disciplines with a high level of numeracy, development of computing technology, or both.

These correspond roughly to "Core STEM" fields used in other reports (Bosworth *et al.*, 2013; GAO, 2014). According to this approach, STEM does not include those fields that use information and capabilities *derived from* science, technology, engineering, and mathematics, nor does it include health care or social sciences fields.

1 STEM fields of study determined by Statistics Canada; detailed descriptions generated by the Panel.

The Panel also sub-divided "non-STEM" fields, to provide meaningful comparisons with Statistics Canada's STEM groups, recognizing the considerable variation in outcomes among graduates of both STEM and non-STEM fields. The non-STEM groups examined include:

- **Applied Science & Technology:** fields that use knowledge derived from STEM fields, but were not deemed by Statistics Canada to primarily advance the frontiers of core STEM knowledge (e.g., agriculture, environmental, architecture, accounting, and technical programs). Although these are fields of research and generate knowledge, they are not considered to contribute to core areas of STEM knowledge.
- **Medical and Health-Related Fields:** including clinical programs and health-care-related programs.
- **Social Sciences:** including anthropology, economics, geography, psychology, and legal studies.
- **Humanities and Arts:** including philosophy, history, languages, music, fine arts, and creative design programs.
- **Other fields:** not elsewhere classified, including a mix of business, multidisciplinary, professional programs (e.g., legal, education), and fields not included in any of the above groups.

The Panel recognizes that other types of skills and knowledge are needed in combination with STEM skills for innovation and economic growth, including entrepreneurship, art, and creative design. Many have called for inclusion of the "Arts" in the discussion of important skills for innovation, giving rise to the STEAM acronym. The focus of this report is specifically on those core fields in science, technology, engineering, mathematics, and computer sciences that contribute to innovation through knowledge generation and technology development, in accordance with the classification developed by Statistics Canada (StatCan, 2013b). A definition that is too broad may hamper its utility, or lead to confusion.

Any classification system will have limitations and disadvantages, depending on the context and the way it is used. The Panel has chosen to apply the existing classification developed by Statistics Canada for consistency with available analyses of Canadians with a STEM education. This classification system clearly does not capture all STEM skills in the Canadian population, or all fields that use or apply some form of STEM skills or knowledge. Nevertheless, they are indicators of the supply of graduates with education in a core STEM field. Although researchers and policy-makers are generally more interested in STEM skills per se, data on field of education are more easily available. Thus, these data are often used as a general indication of the types of STEM skills available to an individual or at the population level.

Post-secondary programs at the bachelor's level and above in STEM fields prepare their graduates with advanced STEM skills, as described in the previous section. Although types of STEM skills are broadly associated with levels of education, the Panel recognizes that they can be learned in a variety of training or occupational settings, both formal and informal. For example, computer programming can be learned formally in a certificate program focused on a particular programming language or problem type, as part of a broader degree at the undergraduate level or above, or through recreational or professional activities outside of the formal education system. Therefore, STEM skills of all types are not exclusively learned through education in a STEM field.

Table 1.1 summarizes the Panel's understanding of the relationship between skill types (as described in the previous section) and STEM fields and levels of education (as described here). Throughout this report, *STEM graduates* refers to people whose highest post-secondary credential is at the college certificate or diploma level or above, and in a STEM field. *STEM degree-holders* refers to people whose highest degree is at the undergraduate level or above in a STEM field.

Table 1.1

Terminology Relating STEM Skills to Level and Field of Education

<table>
<tr><th rowspan="2">Level of Post-secondary Education</th><th rowspan="2">ISCED* (and OECD) Equivalent</th><th colspan="2">Terms Used in this Report</th><th colspan="2">Field of Education</th></tr>
<tr><th>Graduates</th><th>Degree-Holders</th><th>STEM</th><th>Non-STEM</th></tr>
<tr><td>Earned Doctorate</td><td>Advanced Research programmes (ISCED level 6)</td><td>○</td><td>○</td><td rowspan="2">Advanced STEM skills</td><td rowspan="4">Practical STEM skills</td></tr>
<tr><td>Master's Degree</td><td>Tertiary Type A (ISCED 5A: second and further degree)</td><td>○</td><td>○</td></tr>
<tr><td>Professional Degrees (Above Bachelor Level)</td><td>Tertiary Type B (ISCED 5B: second qualification)</td><td>○</td><td>○</td><td>Practical STEM skills</td></tr>
<tr><td>Undergraduate (Bachelor's) Degree</td><td>Tertiary Type A (ISCED 5A: first degree)</td><td>○</td><td>○</td><td>Advanced (+ Practical) STEM skills</td></tr>
</table>

continued on next page

<table>
<tr><th rowspan="2">Level of Post-secondary Education</th><th rowspan="2">ISCED* (and OECD) Equivalent</th><th colspan="2">Terms Used in this Report</th><th colspan="2">Field of Education</th></tr>
<tr><th>Graduates</th><th>Degree-Holders</th><th>STEM</th><th>Non-STEM</th></tr>
<tr><td>Certificate, Diploma, or Technical Training (Below Bachelor Level)</td><td>Tertiary Type B (ISCED 5B)</td><td>o</td><td>X</td><td rowspan="2">Practical STEM skills</td><td rowspan="2">Practical STEM skills</td></tr>
<tr><td>Trades Certificate or Apprenticeship</td><td>Post-Secondary Non-Tertiary: Vocational or Technical Education (ISCED level 4)</td><td>X</td><td>X</td></tr>
</table>

*International Standard Classification of Education (ISCED) terminology from UNESCO (2006)

Although practical STEM skills, as defined in Section 1.2.1, are associated with post-secondary training in a STEM field at the level of certificates and diplomas below the bachelor's level, they may also be associated with other fields of study at *any* level. For example, although STEM doctoral programs are focused on advanced skills, graduates may also develop practical skills throughout the course of their research; similarly, architecture is not considered a STEM field (according to Statistics Canada's classification), but graduates develop and require many practical STEM skills as part of their studies. Grey boxes indicate programs that are not included in the Statistics Canada classification of "STEM fields." Skills may be defined conceptually and independently of formal education or other learning environments, but data on levels and fields of education are more readily available to researchers and policy-makers. Note that credentials at many levels are available at multiple types of institutions, including colleges, polytechnics, and universities. Only doctorates are exclusive to universities. "Post-secondary credential" includes all levels of education depicted. "Graduates" refer to all individuals with a post-secondary education at the college certificate or diploma level and above (i.e., excluding trades certificates and apprenticeships), represented by circles. "Degree-holders" include those with a bachelor's degree and above.

1.3 THE PANEL'S APPROACH

The Panel met four times over the course of 2013 and 2014 to review evidence and deliberate on the charge. In its deliberations, the Panel relied on two main sources of evidence: a comprehensive literature review, and a new analysis of educational and occupational data on STEM skills. In the absence of strong or conclusive data, Panel members invoked their collective expertise to analyze the evidence and draw their own conclusions. These instances are noted throughout the text.

Peer-reviewed studies in academic journals were prioritized in the literature review, but government documents and reports from independent think tanks were considered where relevant. Literature from a range of domains was examined, including economics, education, sociology, cognitive science, and political science. While the Panel reviewed relevant evidence from business surveys, it noted the limitations of these types of data. In general, the Panel prioritized studies with direct bearing on the Canadian context; however, many patterns with respect to the development and application of STEM skills in a modern economy are not unique to Canada. As such, literature building on studies from the United States, Europe, and other industrialized economies informed the Panel's findings. The Panel only considered studies it deemed to be of high quality and sufficient rigour.

The Panel analyzed a significant amount of existing data from from Statistics Canada and other sources. This included: (i) a new analysis of historical census data with harmonized fields of study across time periods; (ii) an analysis of recent labour market outcomes in tax records for a cohort sampled from respondents to the 2006 Census; (iii) an analysis of graduation trends from Canadian post-secondary institutions; (iv) an analysis of various sources of Canadian labour market data such as the Labour Force Survey; and (v) a review of other data sets relevant to educational and employment outcomes in Canada. OECD data were used to provide international comparisons, particularly results from the Programme for International Student Assessment (PISA) and the Programme for the International Assessment of Adult Competencies (PIAAC).

It is important to note that major changes in survey methods, such as the 2011 replacement of the mandatory long-form census with the voluntary National Household Survey (NHS), can affect the quality and comparability of data over time. For this reason, historical trends presented in this report do not include the 2011 NHS. Rather, NHS data are used to present the most current snapshots of the Canadian population. With the NHS, Statistics Canada classified individuals into STEM and non-STEM fields of study for the first time (according to the definition presented in Section 1.2.2). The Panel worked with Statistics Canada to define analogous groups in historical data sets, but again, due to differences in methodology between the NHS and previous censuses, the data are not directly comparable.

To ensure that its deliberations did not neglect key aspects of the current Canadian business environment, the Panel interviewed several entrepreneurs. These individuals described their experiences relating to STEM skills, and their opinions on the role of these skills in supporting the creation of new technology firms in Canada, and the degree to which existing post-secondary educational institutions and programs in Canada are effectively training the next generation of STEM workers. Their input helped frame the Panel's approach, to ensure that important issues were considered, but did not constitute evidence related to any of the Panel's findings.

1.4 REPORT FRAMEWORK

Based on this approach, the Panel developed an analytical framework for the report, as shown in Figure 1.1. Since innovation and productivity growth are the outcome of both the supply of skills, including STEM, and how they are applied in the labour market (demand), the Panel chose to first explore the **role of STEM skills in innovation and productivity growth** (Chapter 2). It then looked at what is known about the **current dynamics of STEM skills** in the Canadian labour market (Chapter 3). Such dynamics are determined by the forces of supply and demand, and are expressed through the presence or absence of labour market imbalances and skill mismatches (sometimes referred to as shortages or surpluses). The Panel then turned its attention to **future demand for STEM skills** in Canada, which is affected by many factors that are difficult to predict (Chapter 4). These include the effects of rapidly evolving technologies, the results of labour market forecasts, global competition, and the offshoring of work.

In a functioning labour market, demand is balanced with supply. The Panel then assessed the **STEM skill supply flows** from three key sources: fundamental skills for STEM, which drive STEM literacy, developed in the **domestic education system** from early childhood education through Kindergarten to Grade 12 (Chapter 5); and the practical and advanced STEM skills developed through **post-secondary education**, **workplace training**, and **lifelong learning**, (Chapter 6) and gleaned from the global market through **immigration** (Chapter 7).

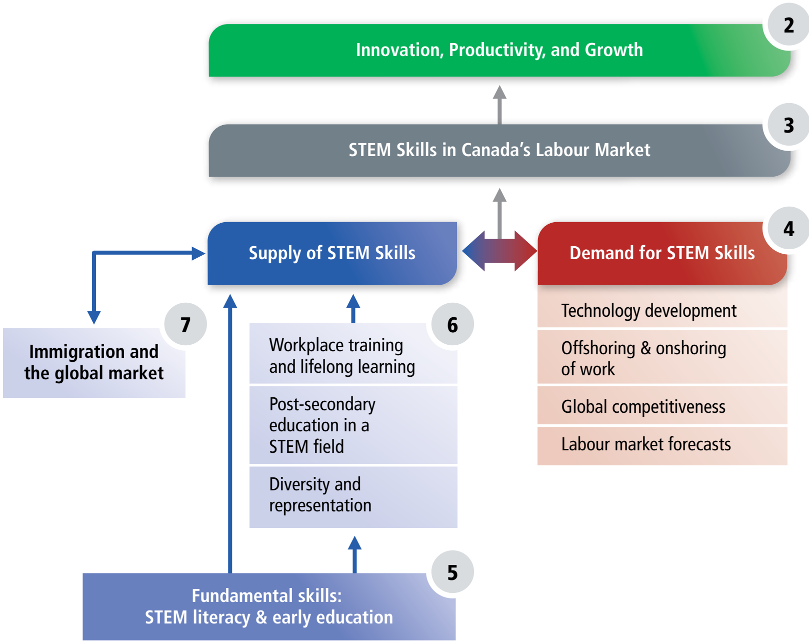


Figure 1.1

Analytical Framework for the Assessment

The numbers in the figure indicate the chapter in which each component of the framework is discussed.

More specifically, the focus of each chapter is as follows:

Chapter 2 explores the relationship between STEM skills, innovation, and productivity. It describes the theoretical basis for understanding the role of STEM skills in the economy and presents the available empirical evidence on the impact of STEM skills on productivity growth and other economic outcomes.

Chapter 3 examines Canada's current supply of practical and advanced STEM skills. Focusing on key indicators such as relative wages and employment rates, it provides evidence to inform the debate about skill needs and the extent to which labour imbalances do or do not exist at the national level.

Chapter 4 surveys evidence on how demand for STEM skills is currently evolving in Canada and how it may evolve in the future. The Panel reviews data from occupational projection systems, as well as studies that characterize how the nature of work is changing. It also assesses the importance of fundamental, practical, and advanced STEM skills, along with complementary skills, in an uncertain labour market.

Chapters 5, 6, and 7 look at the roles of different supply sources in (i) meeting the future demand for STEM skills in Canada, and (ii) providing the other skills needed to give Canadians a broad range of education and career options in an uncertain labour market.

Chapter 5 explores the concept of STEM literacy in society, documenting the importance of fundamental skills for STEM to a variety of occupational and social settings, beyond those associated with professional scientists and engineers. Typical pathways for STEM skills development in the Canadian education system from early childhood through to the end of high school are discussed.

Chapter 6 discusses the respective roles of post-secondary education, workplace training, and lifelong learning in meeting demand for practical and advanced STEM skills in the Canadian labour market.

Chapter 7 investigates the role of immigration, emigration, and skill transferability in the context of an increasingly global market for highly specialized and advanced STEM skills.

Chapter 8 summarizes the Panel's main findings and conclusions in response to its charge. It also notes key gaps and weaknesses in the evidence, and identifies promising strategies for filling those gaps in the future.

Appendices are available online with additional details on data sets analyzed for this report. They include detailed statistics on the composition, employment rates, and earnings of Canadians with STEM and non-STEM post-secondary credentials.

2

The Relationships Among STEM Skills and Innovation, Productivity, and Growth

2 The Relationships Among STEM Skills and Innovation, Productivity, and Growth

Key Findings

Innovation and investment in human capital and physical capital drive productivity growth. STEM skills may contribute to each of these channels to boost productivity.

At the aggregate level, individuals with post-secondary STEM education are paid a wage premium compared with those with equivalent years of non-STEM education. This suggests that STEM training tends to boost relative productivity, but there is significant variation by gender, sub-field, and occupation of employment.

Wages alone do not capture the full value of STEM skills to the economy. STEM skills can generate large external benefits beyond the individual. For example, they can promote innovation through development of new technologies and promote the adoption of new types of physical capital. However, there are many types of innovation, and not all of them depend on STEM skills.

There is limited evidence identifying the specific contribution of advanced STEM skills to productivity growth and innovation or the magnitude of these effects. The analysis required to isolate the contribution of STEM skills from that of other skills and factors is very difficult and relevant data are often unavailable.

In the Panel's view, the balance of evidence on the impact of STEM skills on innovation suggests that they generate significant benefits.

Upon reviewing the evidence, it is the judgment of the Panel that STEM skills represent an important but not sufficient condition for innovation, productivity, and economic growth.

Science, technology, engineering, and mathematics are dynamic fields of study that continue to yield a multitude of discoveries and innovations that benefit Canadians in all walks of life. This chapter reviews the evidence on how STEM skills are linked to productivity and economic growth, beginning with a brief introduction to productivity. Productivity is driven by innovation, human capital, and physical capital, and STEM skills could raise productivity through each of these channels. While many claims have been made about the relationships between STEM and productivity, the Panel finds limited supporting evidence because of the difficulties inherent in such an analysis.

2.1 THE PRODUCTIVITY FRAMEWORK

Labour productivity is the amount of goods and services produced per hour worked (see also Box 2.1). As such, productivity growth is the key factor for growth in living standards in the long run. Since 2000, productivity growth in Canada has been poor, relative to other countries and Canada's own historical levels. Between 2000 and 2013 output per hour worked in the Canadian business sector increased at a compound annual rate of 0.8% (StatCan, 2014l), compared with 2.2% in the United States (BLS, 2014). This rate was 1.5% in Canada from 1981 to 2000. Canada ranked sixth last out of 33 OECD countries in growth in gross domestic product (GDP) per hour worked from 2001 to 2013 (OECD, 2015).

Modern growth theory identifies three drivers of labour productivity growth: accumulation of human capital, accumulation of physical capital, and the rate of innovation (Figure 2.1). Productivity performance is determined by the quantity and quality of these interconnected factors, combined with how they are organized, managed, and used in firms (Rao *et al.*, 2001). STEM skills could play an important role in strengthening each driver of productivity growth.

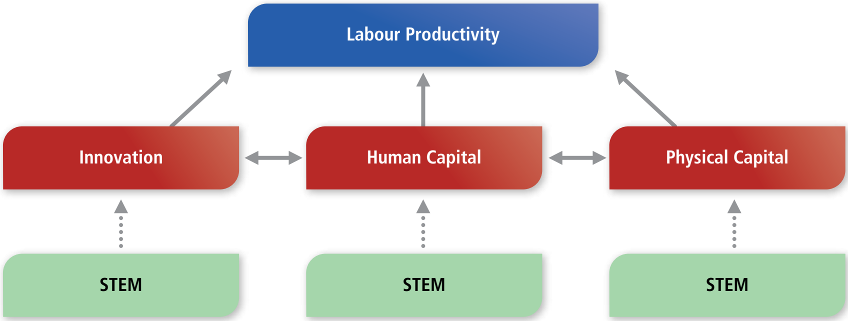
Box 2.1
Understanding Productivity

Productivity is the amount of output generated per unit of input. In addition to *labour productivity* (defined above), there are several different ways to measure productivity. The appropriate measure depends upon the purpose of the measurement.

Partial productivity metrics relate output to one input, such as labour or capital, while *multifactor productivity* (MFP) metrics relate output to a combination of inputs. *MFP growth* is defined as the growth rate of output minus the growth rate of the combined inputs. Various weights may be assigned to the different inputs to construct the combined input. The standard approach is to weight each input by its current-dollar income share because, in competitive markets, this is usually thought to equal the relative contribution of the input to total output.

The interpretation of MFP is controversial. Some economists claim that it measures overall technical change, others that it only captures disembodied technological change, and some even claim that it does not measure technological change at all. Since it is calculated as the residual output growth that cannot be explained by input growth, MFP captures other factors besides technological progress. These include things such as measurement error, increased capacity utilization rates, or realization of economies of scale.

(Sharpe, 2002)



Adapted from FC (2004)

Figure 2.1

The Productivity Framework: Links with STEM Skills

The framework depicts the relationships between labour productivity and its constituent parts. This body of economics research is relatively well defined (see Rao *et al.*, 2001; FC, 2004). Less is known about how STEM skills apply to this framework.

Human capital refers to all the skills, abilities, and knowledge embodied in people. While some abilities are innate, to varying degrees, individuals can acquire more human capital through formal education, workplace training, and experience. Investment in human capital increases the amount of output that workers are able to produce. Variables such as educational attainment, years of experience, or standardized test scores are often used as proxies for general human capital. STEM skills are a component of human capital, allowing workers to do more technical tasks and identify more efficient ways of doing their jobs.

Physical capital captures investment in physical equipment such as plant and machinery, as well as infrastructure investment like electricity grids and pipelines. Greater investment in physical capital allows workers to produce more and higher-quality output for each hour they work. STEM skills could play a role in increasing physical capital's contribution to productivity through improving its operation and use. Individuals with more STEM skills could get more out of the latest equipment, such as being better able to fine-tune software. STEM skills could also be important in being aware of and adopting the latest pieces of equipment.

Innovation, the source of new or improved products or processes, is essential to economic competitiveness and social progress (CCA, 2013a). The *Oslo Manual* (OECD/Eurostat, 2005) defines innovation as "the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organisational method in business practices, workplace organisation or external relations." Workers and researchers with STEM skills can play an important role in innovation by developing new products and production processes. Entrepreneurs with STEM knowledge can recognize opportunities to start new businesses. Firms prefer to invest in R&D and cutting-edge technologies in regions (clusters) where workers possess specialized STEM skills that will complement their investments (see Head *et al.*, 1999).

2.2 THE ROLE OF STEM SKILLS IN THE PRODUCTIVITY FRAMEWORK

There is a large amount of evidence on the importance of human and physical capital and innovation in promoting productivity growth. The Panel decided not to review this literature but to concentrate instead on the evidence on the role of STEM skills and productivity. Although there are reasons to think that links between STEM skills and productivity exist, there is no extensive body of research on these effects. This is largely due to difficulties in obtaining appropriate data. As a result, direct evidence is limited to a few studies.

One of the ways of capturing the role of human capital is to look at wages. Several factors affect wages, including productivity. Thus, studies often use wages as an indicator of labour productivity. One of the most commonly cited pieces of evidence of the importance of STEM skills to productivity is the wage premium commanded by workers with STEM credentials or working in STEM occupations. The following wage analysis relates to productivity effects that are captured by a STEM worker; it does not reflect productivity effects that benefit other agents in an economy, referred to as *externalities*. Such externalities are captured in Section 2.4.

Economic theory posits that, in equilibrium, the payments to workers and capital are equal to their productivity in competitive markets. A higher hourly wage suggests that a worker is contributing a greater amount to the total value of output for each hour worked. Other things being equal, the assumption in the Panel's following analyses is that the worker becomes more productive as he or she acquires more human capital.

The evidence is clear that workers with post-secondary credentials tend to earn higher wages than those without such credentials. Evidence from linked Canadian census data and the Longitudinal Worker File for 1991 to 2010 shows that the 20-year earnings premium associated with a bachelor's degree ranges from $442,000 (women) to $728,000 (men). The college premium ranges from $180,000 (women) to $248,000 (men) (Frenette, 2014).[2,3] When parental education and skills are accounted for (based on the 2003 International Adult Literacy and Skills Survey), the relationships still hold, although the earnings premium decreases by about one-third (Frenette, 2014). Field of study is unaccounted for; thus while premiums may indeed be higher for some fields than others, these results attest to the general value of a post-secondary education (see Chapter 6 for more on post-secondary education in Canada).

For STEM-specific education, results are mixed. Data from the 2011 NHS reveal that in 2010, university graduates between the ages of 25 and 34 who majored in STEM fields earned a median annual salary of $59,300, compared with a median salary of $52,200 earned by non-STEM majors (Hango, 2013). However, notable differences exist among sub-fields and between men and women. For example, engineering graduates earned a median salary of $65,200, but science graduates earned $51,700 — less than the median salary of a non-STEM graduate. Earnings differences between STEM and non-STEM graduates were twice as large for men as they were for women. Thus, generalizations about the extent to which a STEM degree is associated with a higher salary can obscure important differences by field of study and gender.

A different study found that in 2007, employed PhD graduates in computer sciences, mathematics, and physical sciences earned a median annual income of $60,000 two years after completing their programs at Canadian universities — the same as humanities graduates (Desjardins & King, 2011).[4] By comparison, the median income across all fields was $65,000.[5] Thus, PhDs in these STEM fields did not earn a premium relative to the median PhD holder. Engineering graduates, however, earned a median income of $70,000. This too emphasizes the influence of specific fields of study, rather than broad STEM or non-STEM groupings.

Other evidence comes from a cohort analysis of University of Ottawa undergraduates (Finnie & Childs, 2014). Thirteen years after graduation (in 2011), individuals with degrees in engineering and computer sciences, business, and mathematics and natural sciences had the highest mean earnings. However, these graduates experienced considerable volatility in their earnings over time,

2 Most attempts to estimate lifetime premiums have been riddled with a number of questionable assumptions, but this research is able to avoid some of them by estimating the long-term benefits of post-secondary investments for one cohort of 30- to 50-year-old Canadians.

3 These premiums are relative to a high school degree and are presented in 2010 constant dollars. They are not present values.

4 The study draws upon data from the National Graduates Survey. The figures only include graduates from 2005 who were still in North America in 2007.

5 These figures may underrepresent the wages of those with graduate degrees to the extent that they are lowered by the inclusion of graduates who went on to pursue post-doctoral studies.

suggesting greater vulnerability to fluctuations in the business cycle. In contrast, health, social sciences, and humanities graduates experienced less volatility, with smaller but steadier increases in earnings. Again, there were significant differences in earnings between women and men. These results attest to the value of a long-term perspective for understanding earnings patterns after graduation, but the Panel noted that the groupings cast doubt on the extent to which these differences can be generalized: a petroleum engineer will likely earn more than a computer technician, for example.

Table 2.1 presents information from the Labour Force Survey on the 2014 wages of full-year, full-time workers aged 15 and over in Canada by occupational group. "Natural and applied sciences and related occupations" is not representative of all STEM workers, but it is one of the most STEM-intensive occupational groups, with a majority of workers having a STEM education (see Chapter 3).[6] The average hourly wage earned by workers employed in these occupations was $34.55, compared to the national average hourly wage of $26.17. Only those in management occupations earned higher wages. Again, while this is informative to some extent, the Panel cautioned against drawing conclusions that do not account for potential differences within occupational categories.

Extensive research on demand, supply, and rates of return to STEM occupations has been conducted in the United Kingdom. Overall, U.K. graduates have high employment rates, with relatively little difference between those of STEM graduates and non-STEM graduates (DIUS, 2009). STEM graduates tend to have higher earnings than non-STEM graduates, but wage returns to physical sciences, mathematics, computing, and engineering are higher than average, whereas biology and other biological sciences (e.g., psychology) tend to be lower than average. Any positive earnings differential garnered from studying STEM may be lost if a STEM career is not pursued (DIUS, 2009; Greenwood, 2011). The authors conclude that once occupation is accounted for, the STEM wage premium is mainly for STEM graduates who work in science and finance-related occupations (DIUS, 2009).

6 Chapter 3 provides evidence that qualifications and occupations do not directly align; all STEM-intensive occupations employ non-STEM degree-holders.

Table 2.1

Average Wages of Full-Time Workers in Canada, by National Occupational Classification for Statistics (NOC-S) Code, 2014

Occupation	Average Hourly Wage (2014 $)	Relative to National Average (%)
Management occupations	39.86	152.31
Natural and applied sciences and related occupations	34.55	132.02
Occupations in social science, education, government service and religion	31.99	122.24
Health occupations	28.66	109.51
Occupations in art, culture, recreation and sport	26.41	100.92
Total employees, all occupations	26.17	100.00
Trades, transport and equipment operators and related occupations	24.97	95.41
Business, finance and administrative occupations	24.37	93.12
Occupations unique to primary industry	23.26	88.88
Occupations unique to processing, manufacturing and utilities	20.94	80.02
Sales and service occupations	18.50	70.69

Data Source: StatCan (2014h) and Panel calculations

Based on Labour Force Survey data, this table presents average hourly wages for full-time workers aged 15 and over in Canada. Data in right column calculated by Panel, based on average hourly wage data from Statistics Canada (left column).

Consistent with other studies, Greenwood (2011) finds that U.K. STEM qualifications are not all alike: qualifications in certain science occupations often do not attract high-wage premiums, whereas those in engineering and technology often do. In other words, some STEM qualifications are more valuable than others. Further, while earning a doctorate generates a lifetime earnings premium relative to holding a bachelor's degree, the gains over doing a much shorter master's program are very small in many fields (Casey, 2009). Also in the United Kingdom, Casey (2009) finds that while doctoral degrees command an earnings premium relative to master's degrees in the sciences and business and financial studies, doctoral degrees in mathematics and computing generate no earnings premium over a master's degree, and doctoral degrees in engineering and technology generate a relatively smaller earnings premium.

Generally, the evidence indicates that the effect of a STEM degree on wages and earnings premiums is mixed. At first glance, some studies appear to reveal a STEM education premium. To the extent that wages are indicative of labour productivity, this is evidence that, at the aggregate level, STEM workers are more productive than non-STEM workers. However, further analysis suggests that differences among STEM and non-STEM sub-fields may challenge this assumption. Large categorizations of STEM and non-STEM may blur variations among their constituent fields. One shortcoming of most of these studies is that they do not indicate much about causation. Further, earnings are affected by more than education. Experience (as demonstrated in the Mincer earnings function) (Mincer, 1958) plays a direct role, and complementary skill sets are also implicated (see Chapters 4 and 6). Thus, STEM skills appear to be important but not sufficient for increasing productivity.

Regardless of conclusions on direct wage effects, STEM skills also help indirectly because their skills can lead to positive spillovers or externalities to the rest of the economy. In other words, there can be social benefits of STEM that are not captured in wages. The role of STEM skills in producing new knowledge and ideas is critical in this discussion. Knowledge and ideas are distinct from most goods and services in that one person's use of an idea does not prevent another individual from also using the idea. Once knowledge exists, it can benefit a large number of people. This nature of knowledge and difficulties in limiting its dissemination can often mean that individuals and firms cannot fully capture the value of ideas that they generate. This inability to capture the full value of an innovation suggests that the relative wages paid to STEM workers may under-represent the relative value of their work to society over time.

The Panel acknowledged that STEM skills are unusual in that they potentially generate large externalities: the social benefits from innovation may greatly exceed the private benefits to STEM workers, as measured by their wages. Consequently, workers may underinvest in STEM skills compared with what is socially optimal. A thorough assessment of the impact of STEM on productivity should include the benefits from these externalities.

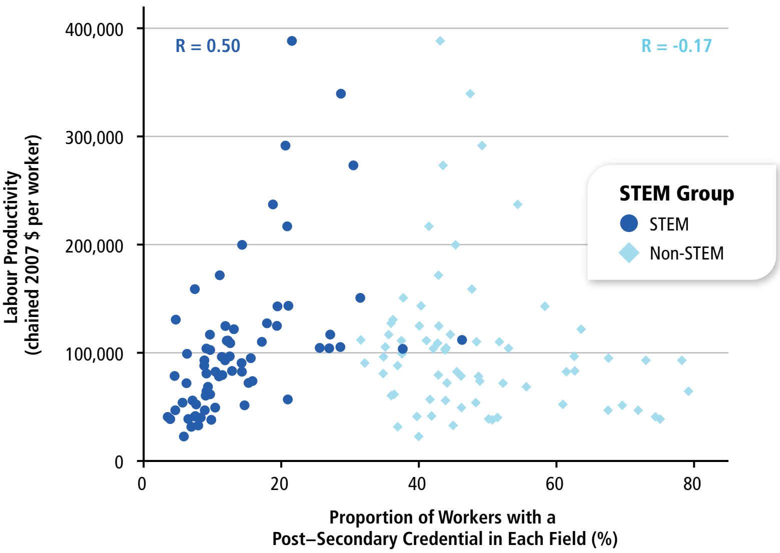
2.3 STEM AND AGGREGATE LABOUR PRODUCTIVITY

In practice, and as demonstrated by this section, it is difficult to disentangle the contribution of STEM workers to productivity from other factors. Theoretical links exist but research has yet to determine the precise contributions of the relevant factors. A preliminary investigation of the relationship between STEM education and productivity includes a comparison across industries, countries, and time. STEM employment shares are used as a measure of STEM skills. Eurostat data show that the share of the European population with a post-secondary education employed in science and technology[7] increased between 2000 and 2010 (Eurostat, 2014a). This is correlated with rising labour productivity levels (Eurostat, 2014b). Such a correlation is evident within and across countries. However, conclusions cannot be drawn about causality because a high degree of correlation also exists between these two variables and many other factors (e.g., GDP per capita). As an alternative, the Panel investigated a potential correlation between productivity growth rates (instead of levels) and the population share of those with tertiary education employed in science and technology. If STEM workers are a major source of productivity growth, one might expect that countries with more workers in science and technology would tend to have faster growth rates. However, Eurostat data do not reveal a correlation (Eurostat, 2014a, 2014b). Using the same data set, the Panel also determined that growth rate in labour productivity across countries does not appear to be correlated with growth rate in the share of adults working in science and technology.

A different approach is to look for a correlation between labour productivity in Canada and the STEM intensity of the workforce across industries. Using data on GDP and employment, both disaggregated by industry, the Panel calculated labour productivity (value added per employed worker) for these same industries. It found that the level of labour productivity in 2010 was positively correlated with the proportion of STEM degree-holders in an industry, although the correlation is weak (Figure 2.2) (StatCan, 2014d, 2014g).[8] Although this is consistent with the idea that STEM workers raise productivity, it is not sufficient evidence to establish a causal relationship. In contrast with the correlation depicted in Figure 2.2, further analysis did not reveal a correlation between average labour productivity growth rates from 2009 to 2013 for Canadian industries and the proportion of workers in those industries with a post-secondary credential in a STEM field (STEM intensity).

7 Note that the definition of *science and technology* used by Eurostat data on human resources in science and technology (HRST) does not correspond to the definition of STEM used by the Panel. For example, the HRST definition of *occupation* includes those working in the social sciences. For details on the HRST definitions employed in the Eurostat data, see http://ec.europa.eu/eurostat/cache/metadata/Annexes/hrst_esms_an1.pdf.

8 Two outliers have been removed from analyses of these data. These are *real estate* and *oil and gas extraction*, which had labour productivities of $980,000 and $1.62 million per worker employed respectively and 10.0% and 30.3% of their workers possessing post-secondary qualifications in STEM fields. Inclusion of these outliers weakens the correlation somewhat (R = 0.32), but it remains weakly positive.



Data Source: StatCan (2014d, 2014g, 2014n) and Panel calculations

Figure 2.2

Average Labour Productivity and STEM Intensity by Industry (3-digit NAICS codes) in Canada, 2011

The x-axis shows the proportion of workers aged 25 to 54 in the sector whose highest post-secondary credential is in a STEM (dark blue) or non-STEM (light blue) field (StatCan, 2014n). The y-axis shows the level of labour productivity in a sector in 2011, calculated as GDP (from StatCan, 2014d) divided by the total number of workers employed (from StatCan, 2014g). Out of 75 industries at the 3-digit North American Industry Classification System (NAICS) level, this figure shows that labour productivity is higher in industries with a larger proportion of workers aged 25 to 54 whose highest post-secondary credential is in a STEM field (STEM intensity). As demonstrated by the correlation coefficient (R), there appears to be a weak positive correlation between the proportion of workers with a STEM credential and labour productivity (R = 0.50). This correlation does not necessarily indicate causality. There appears to be no correlation (R = -0.17) between sector labour productivity and the proportion of workers whose highest post-secondary credential was in a non-STEM field.

2.4 ESTIMATES OF THE EFFECTS OF STEM ON INNOVATION AND PRODUCTIVITY

The remainder of the chapter presents the existing evidence on what is known about the direct estimates of the effects of STEM on innovation and productivity, respectively.

2.4.1 Estimates of the Effects of STEM on Innovation

Overall, scientists and engineers can play a part in the production of innovation, and some authors have used them to try to identify the sources of technological progress (Griliches, 1992; Jones, 1995). For example, Jones (2002) performed a growth accounting exercise in which he attributed 50% of U.S. productivity growth between 1950 and 1993 to “research intensity” in the G5, which is measured by the number of scientists and engineers engaged in R&D.

Consistent with the idea that innovative firms are more likely to employ STEM skills, the 2013 U.K. Innovation Survey reveals that, on average, 12% of employees in innovative firms in the United Kingdom possess a degree in science or engineering compared with only 4% in non-innovative firms (Hooker & Achur, 2014). The one study that has addressed this issue directly for a subset of STEM workers finds that the number of “star” scientists and engineers in a field in a given region or cluster has a large effect on the likelihood of firms starting up in that field (Zucker, 2006).

The most direct evidence of the impact of STEM on innovation comes from a few recent studies that investigate STEM’s effect through the immigration of skilled workers. These studies generally find evidence that STEM-skilled immigrants increase innovation, but it is not clear to what extent the effects of changes in the number of foreign STEM workers are representative of the effects of changes in STEM workers more generally.

Hunt and Loiselle (2010) show that immigrants account for 24% of patents in the United States, which is twice their share in the population. The immigrant patenting advantage over non-immigrants is entirely accounted for by immigrants disproportionately holding degrees in science and engineering fields. Using aggregate data from the U.S. Patent and Trademark Office and censuses, as well as individual data from the National Survey of College Graduates, they find evidence of positive spillover effects of foreign immigrants on patenting. A 1 percentage point rise in the share of immigrant college graduates in the population increases patents per capita by 9 to 18%. In other words, beyond a basic increase in the number of STEM workers, patents per capita represent a positive spillover, or benefit, in terms of levels of invention. They show that immigrants who are scientists and engineers, or who have post-graduate education, increase patents per capita more than immigrant college graduates (Hunt & Gauthier-Loiselle, 2010).

Kerr and Lincoln (2010) find that the H-1B visa program for temporary foreign workers has played a significant role in U.S. innovation over the last 15 years. They discover that fluctuations in H-1B admissions of scientists and engineers significantly influenced the rate of Indian and Chinese patenting in U.S. cities and firms that are dependent upon the program (relative to other cities and firms). They find limited effects for non-immigrant employment or patenting. They conclude that total invention increased with higher admissions, mainly because of the direct contributions of immigrant inventors (Kerr & Lincoln, 2010).

Moser *et al.* (2014) look at the impact of German Jewish chemists who immigrated to the United States after losing their positions at research institutions in Nazi Germany. They find that patenting by U.S. inventors increased by 31% in émigré fields after 1933. Rather than increasing the productivity of incumbent U.S. scientists, the arrival of German Jewish émigrés attracted a new group of domestic U.S. inventors to their fields. The timing of the effects suggests that increased invention resulted from the gradual knowledge transfer and learning that occurred after the arrival of émigrés, which continued well into the 1950s. In other words, émigré professors helped increase U.S. invention in the long run, by training a new group of younger U.S. scientists who in turn trained others (Moser *et al.*, 2014).

Borjas and Doran (2012) consider a similar natural experiment: the entry of mathematicians into foreign knowledge markets following the collapse of the Soviet Union. Their findings focus on academic research using a data set of every mathematics paper published internationally, dating back 70 years (Borjas & Doran, 2012). However, they do not find evidence of positive spillover effects on native-born mathematicians. Rather, they discover that U.S. mathematicians whose research fields overlapped with the immigrating mathematicians suffered reduced research productivity and were more likely to relocate to lower-quality institutions. They suggest that émigrés and U.S. mathematicians competed in the academic job and publication markets, which were both fixed in the short term.

Generally, the evidence appears to suggest that innovation is the result of interaction between STEM skills and other factors. Inflows of workers with specialized STEM skills seem to have positive spillovers on domestic innovation in addition to the direct effects of the workers themselves. Studies such as Borjas and Doran (2012) suggest that this is not the case in all markets, and institutional constraints may limit gains. Once the innovations occur, it seems that well-developed human capital is needed to fully take advantage of the new technology, although there is no research indicating the specific importance of STEM relative to other skills in this regard.

In the context of this discussion, the Panel recognized three important points. First, in general, the positive effects of STEM workers on productivity are easier to find when looking at aggregate units (cities/regions) and across fields (e.g., the effects of mathematicians on the productivity of scientists rather than of other mathematicians). As a result, more narrow studies may not reveal such positive impacts. Second, patenting represents a partial and limited account of invention (Griliches, 1990); consider copyright and industrial designs, for example. Not all ideas are patentable, nor are all inventions patented (CCA, 2013b), and some patents do not lead to innovation[9] at all (OECD/Eurostat, 2005). The third, related point is that there are other important types of innovations besides technology-based product and process innovations (Junge *et al.*, 2013). These non-technological innovations include marketing and organizational innovations, and social sciences and humanities skills have been identified as key to these developments (Junge *et al.*, 2013). In both cases, skills such as business acumen, creativity, and risk-taking also play important roles in bringing ideas to market. Thus, the Panel concluded that STEM skills are a contributing factor to innovation, but not the sole driver. Innovation results from the intersection of STEM and non-STEM skills. More research is needed on the nature of this relationship.

The body of research that investigates the relationship between STEM skills and innovation is limited and evidence is light. With this in mind, the Panel concluded that STEM skills contribute to the innovative process, but are not sufficient on their own. In turn, innovation raises productivity. Direct estimates of the effects of STEM on productivity are the focus of the next section.

2.4.2 Estimates of the Effects of STEM on Productivity

Very little academic research attempts to directly estimate the effects of STEM skills on productivity and growth. One of two major studies, conducted by Peri *et al.*, (2014), looks at the impact of foreign STEM workers[10] on productivity in the United States. Peri and Shih (2013) apply the same methodology to a study in Canada. Estimating the causal effect of STEM on non-immigrant wages is difficult because of concerns that positive demand shocks may be driving

9 Invention and innovation are not synonymous. While *invention* refers to a new idea (e.g., as measured by patents), *innovation* refers to the implementation of that idea in useful new or improved products, services, processes, models, and methods (see CCA, 2009).

10 In this study, STEM includes agricultural science and technologies, engineering, applied sciences and related technologies/trades, nursing and nursing assistance, other health professions, and mathematics and physics.

up wages and simultaneously attracting skilled workers. However, the authors introduce a series of controls and robustness checks that provide considerable support for the validity of the methodology.[11]

The results of these recent studies support the idea that foreign STEM workers generate significant spillover benefits for domestic workers. Using data on Canadian cities between 1991 and 2006, they estimate that a 1 percentage point increase in the share of foreign STEM workers in a Canadian region's employment is associated with a positive and significant increase in the wages of non-STEM university-educated Canadian workers in the region by between 2.8 and 6.4 percentage points, depending on the specification used (Peri & Shih, 2013). They also find positive, (though not necessarily significant) effects on the employment of these workers. Since the share of foreign STEM workers in total employment in Canada increased from 2.5% in 1991 to 4.2% in 2006, they estimate that the inflow of foreign STEM workers raised wages of the Canadian university-educated by about 11 percentage points over the period. As national real wage growth of university-educated workers averaged 22% in the same period, the authors suggest that foreign scientists and engineers were major contributors to productivity growth in the Canadian economy (Peri & Shih, 2013). They note that while Canada's immigration policy is selective of highly skilled workers, heterogeneity in the quality of foreign STEM workers (and the interaction of quality with productivity effects) remains an important and under-studied area for future research.

Peri *et al.*, (2014) estimate similar, but slightly larger, effects in the United States. Using the U.S. estimates, they suggest that growth in foreign STEM workers explains between about one-third and one-half of U.S. MFP growth (recall Section 2.1) between 1990 and 2010. The magnitude of these aggregate estimates should be interpreted with caution because regional estimates were applied to make a national inference; effects may be over- or underestimated.

These studies provide preliminary evidence of positive impacts of foreign STEM workers on the non-immigrant population, in the form of wage and productivity gains. The precise magnitude of the effects remains unclear. The focus of the studies is foreign STEM workers, making it difficult to discern whether increasing the number of domestic STEM workers would have a similar impact. This new

11 The identification of a causal effect is based on the idea that foreign STEM workers choose to immigrate to cities where there is an established community of people from the worker's home country. Using the "dependence" of each area in 1981 on foreign STEM workers by nationality of origin and the aggregate growth factors of foreign STEM workers by nationality (proxied using H1-B visas in the case of the United States), the authors constructed predicted increases in the share of foreign STEM workers in the labour force of each area.

evidence suggests that STEM graduates contribute to productivity growth, but the authors do not offer a theoretical explanation for why incoming foreign STEM workers would have generated such large spillovers relative to domestic and pre-existing foreign STEM workers.

2.5 CONCLUSION

A core tenet of standard theories of economic growth is the importance of human capital and technological progress for improvements in productivity and living standards. As a facet of human capital that plays a central role in developing and adopting new technologies, the Panel concluded that STEM skills are an important contributing factor to innovation, productivity, and economic growth. Innovative activity drives growth in productivity and output, and innovation is the primary channel through which STEM skills may boost productivity. However, the Panel also agreed that STEM skills alone cannot drive productivity growth. The full potential of STEM skills may not be realized without the added presence of complementary skill sets to bring innovations to market. Further, there are many types of innovation and not all of them are heavily dependent on STEM skills.

Currently, the most direct estimates of the influence of STEM skills on innovation and productivity are highlighted through the patenting advantage of STEM-skilled immigrants and an analysis of their effects on local wages and productivity, respectively. These studies provide preliminary evidence that STEM-skilled immigrants have positive effects, although the precise magnitude of the effects and the exact means by which they operate are unclear. Further research is required to clarify these links.

3

STEM Graduates in Canada: Shortage or Surplus?

- STEM Graduates in Canada
- Labour Market Outcomes of STEM Graduates: Shortage or Surplus?
- STEM Education and Occupation Matching
- Conclusion

3 STEM Graduates in Canada: Shortage or Surplus?

Key Findings

The available evidence suggests no persistent national imbalance in workers with post-secondary education in a STEM field. Regional and sectoral mismatches may exist, but are difficult to assess with available data.

STEM graduates in Canada are mostly men, and include a greater proportion of immigrants than non-STEM graduates or Canadian adults in general.

Canada ranks high among OECD countries in the proportion of 25 to 34 year-olds with a degree at the undergraduate level or above in life sciences and mathematics and statistics, but very low in computing and engineering fields. Although the share of the population with earned doctorates is lower than in most OECD countries, the majority of them are in STEM fields.

STEM graduates often fare better in the labour market than their non-STEM counterparts, with lower unemployment, higher employment rates, and higher wages on average. But this general pattern obscures considerable variation by gender, level of education, immigration status, and even by STEM field.

Most STEM graduates work in occupations that are not STEM-intensive, but they are more likely than non-STEM graduates to find jobs that make use of their level of education, regardless of occupation.

The chapter begins by comparing Canada's available supply of practical and advanced STEM skills (i.e., STEM graduates; see Section 1.2) internationally. This is followed by a brief review of the composition of STEM graduates in the labour force, since labour market outcomes tend to differ by demographic characteristics, such as gender and immigration status. The rest of the chapter focuses on the overall balance between supply and demand for advanced and practical STEM-skilled labour, based on characteristics and labour market outcomes of STEM graduates. Trends in demand and supply of STEM skills in the Canadian labour market are considered separately in later chapters of the report. This chapter only examines the overall balance between the two. The Panel looked for signs of shortage or surplus at the national level, and tried to ascertain whether these tendencies were persistent or temporary. In doing so, it reviewed a number of indicators, including employment and unemployment data, wages, and matching between education and occupation.

Before beginning the analysis, the Panel recognized that, although STEM skills are not measured directly in national data sets, data exist on both field of post-secondary education and occupation of employment. These each reflect part of a person's skill set acquired through formal education, training, and experience, and can be used as indicators of at least some aspects of specialized STEM skills in the Canadian population.

STEM *graduates* (and *degree-holders*) are those with a post-secondary credential in a STEM field (see Section 1.2), while STEM *workers* are those working in a STEM occupation regardless of educational background. The Panel did not consider detailed data on individuals with trade certificates or apprenticeships because it found the fields of study used to classify other post-secondary programs into STEM or non-STEM to be a poor fit for these groups. Although these levels of education are included in data on the composition of STEM credential-holders as a whole (Section 3.1.2 and Appendix B), they are excluded from data on employment and earnings presented throughout the rest of the chapter (and Appendix C). The Panel defined STEM-intensive occupations based on the proportion of employees who are STEM graduates, but not all workers in a given STEM occupation are STEM graduates. There is considerable overlap between the groups, but they are not synonymous: many STEM workers are STEM graduates, but most STEM graduates are not STEM workers (i.e., they do not work in a STEM-intensive occupation).

3.1 STEM GRADUATES IN CANADA

The Canadian census classifies people by field of study only for their *highest* level of post-secondary education (StatCan, 2013h). This means that even if they have a credential in a STEM field, some people may be classified as "non-STEM" if their highest level of education is in a field that is classified as "non-STEM" (see Section 1.2.2 for STEM fields). Nevertheless, the Panel also recognized that such data are currently the highest-quality data available at the national level for the Canadian population, and provide conservative estimates of the pool of Canadian workers with a STEM education.

Of Canadian adults 15 years of age and older, 9.8% had their highest post-secondary credential in a STEM field in 2011; 12.0% of those who were employed had a STEM credential (Panel calculations using StatCan, 2013i; see also Appendix B). These proportions include all levels of post-secondary education, from trades and apprenticeships to earned doctorates. STEM graduates are thus a notable, albeit relatively small proportion of the Canadian population and employed labour force.

3.1.1 International Comparisons of STEM Degree-Holders

To ensure valid international comparisons, the Panel used data on graduates from the OECD education database, collated from national statistical agencies. These data classify graduates by fields of education described by the International Standard Classification of Education (ISCED) (UNESCO, 2006); only science and engineering degree-holders are included in this analysis. The comparisons described in this section capture only graduates from institutions in each country, whereas the data from Statistics Canada presented in the rest of the chapter include all graduates in Canada, regardless of their location of education. The Panel used data on graduates in each year to estimate the likely number of graduates aged 25 to 34 in each country in 2012; these estimates assume that rates of immigration, emigration, and death are balanced or negligible. Countries with more than five years of missing data, or a gap of longer than three years in the data, were excluded from the analysis, leaving 28 OECD countries for comparison at the tertiary A level and advanced research programs (undergraduate degrees and above; see Table 3.1).

According to these data and calculations, roughly 8.1% of Canadians aged 25 to 34 likely had a degree at the undergraduate level or above in a science or engineering field (Table 3.1). While Canada ranks relatively high among OECD countries in the proportion of young adults with a degree in science fields, the relatively low proportion with computing or engineering degrees brings down Canada's overall ranking (see Table 3.1 and Figure 3.1).

In recent years, the majority of new doctorates in Canada have been in science and engineering fields, and Canada's proportion of new doctorates in these fields has been well above most OECD countries (OECD, 2012c, 2013a). Nevertheless, Canada produces fewer new doctorates as a share of its population than most other OECD countries (CCA, 2012a; CBoC, 2013). The net effect is a relatively low proportion of young Canadians (25 to 34 years old) with a doctorate in science or engineering in 2012: Canada ranks 19th out of 28 OECD countries, despite ranking close to the middle (14th) by the proportion with a doctorate in a science field (see Table 3.1 and Figure 3.2).

Table 3.1

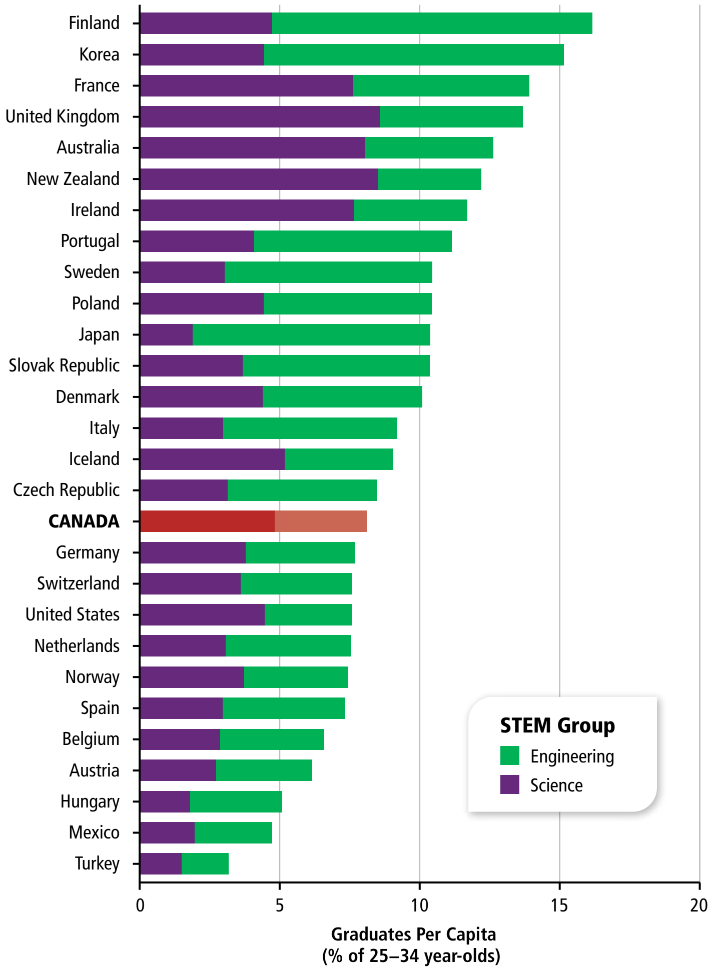
Canada's Rank by Proportion of 25 to 34 Year-Olds with Post-Secondary Education in a Science or Engineering Field, 2012

Education Level	Field of Education	Proportion of 25–34 Year-Olds (%)	Rank	Number of OECD Countries
Advanced Research Programs (PhD)	**Science**	**0.2**	**14**	**28**
	Engineering	**0.1**	**18**	**28**
	Science + Engineering	**0.3**	**19**	**28**
Tertiary A + Advanced Research Programs (undergraduate and above)	**Science**	**4.8**	**7**	**28**
	Life sciences	2.2	5	25
	Physical sciences	0.8	13	25
	Mathematics and statistics	0.5	8	25
	Computing	1.2	19	25
	Engineering	**3.3**	**25**	**28**
	Engineering and engineering trades	2.5	15	25
	Manufacturing and processing	< 0.1	25	25
	Architecture and building	0.7	22	25
	Science + Engineering	**8.1**	**17**	**28**

Data Source: OECD (2014a, 2014b) and Panel calculations

Canada ranks relatively high among OECD countries in the proportion of 25 to 34 year-olds with a degree at the undergraduate level or above in science, particularly life sciences and mathematics and statistics. Canada ranks very low in the proportion of young adults in engineering, and in the proportion of the population with a PhD in general. Although most Canadian doctorate-holders are in science and engineering, this still translates to a moderate to low ranking in the proportion of young adults with a doctorate in science and engineering. The number of graduates in each year from 1998 to 2012 was used to estimate the total number of graduates aged 25 to 34 in 2012, assuming that graduates of tertiary A programs (undergraduate and master's degrees) were aged 22 in the year of graduation, and that graduates of advanced research programs (doctorates) were aged 30. Missing data were imputed, assuming a constant growth rate between known years. Countries with more than five years of missing data, or with a gap of more than three years, were excluded from the analysis.

Canadians with a post-secondary degree at the undergraduate level or above therefore appear to be more concentrated in science fields, particularly life sciences and mathematics and statistics, compared with other OECD countries. This is particularly true at the doctoral level, although overall lower rates of doctoral-holders in the population result in overall low rankings at this level, even in science and engineering.

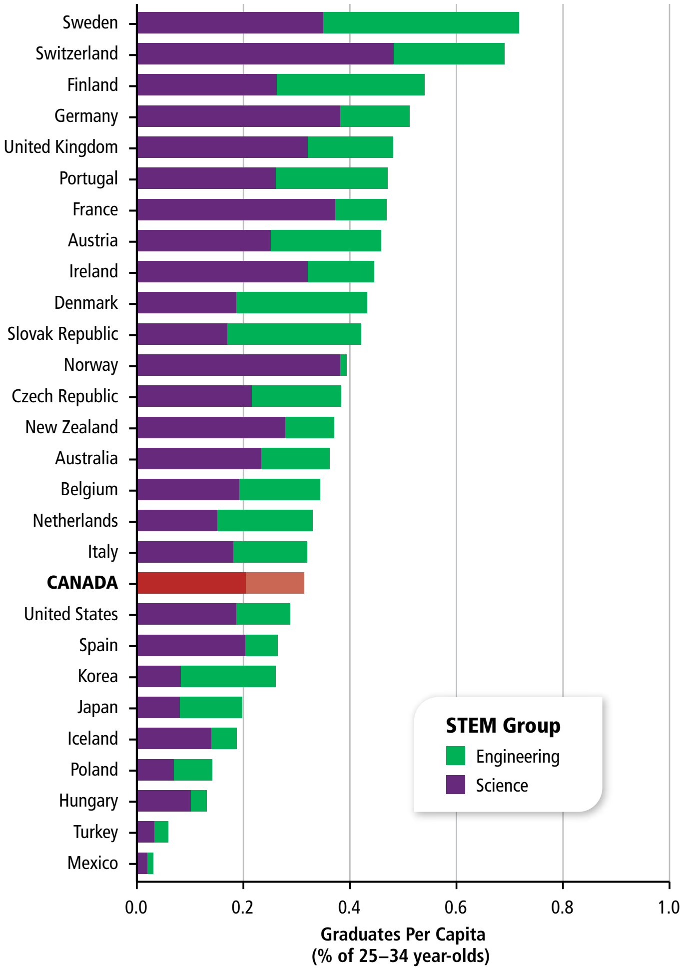


Data Source: OECD (2014a, 2014b) and Panel calculations

Figure 3.1

Proportion of 25 to 34 Year-Olds With a Post-Secondary Degree at the Undergraduate Level or Above in Science or Engineering in OECD Countries, 2012

See Table 3.1 description for assumptions and calculations. Canada ranks 17th out of the 28 countries shown here by the proportion of 25 to 34 year-olds with a science or engineering degree at the undergraduate level or above.



Data Source: OECD (2014a, 2014b) and Panel calculations

Figure 3.2

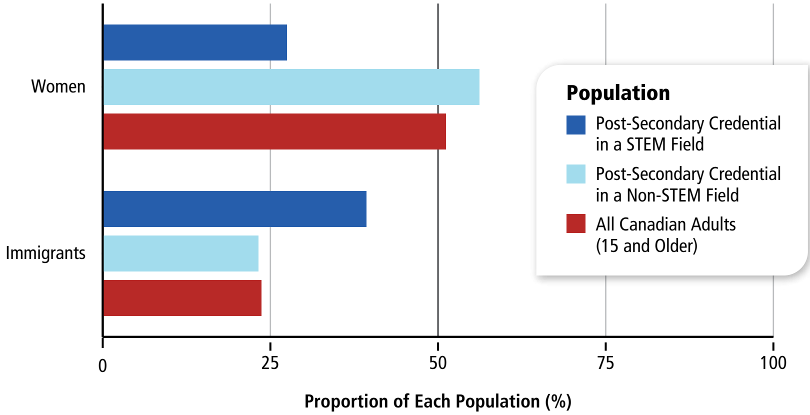
Proportion of 25 to 34 Year-Olds With an Earned Doctorate in Science or Engineering in OECD Countries, 2012

See Table 3.1 description for assumptions and calculations. Canada ranks 19th out of the 28 countries shown here by the proportion of 25 to 34 year-olds with an earned doctorate in science or engineering.

3.1.2 Composition of STEM Graduates

Differences in labour market outcomes may be due to differences in education, training, experience, or innate talents and abilities. Only some of these traits are observable in most data sets: educational credentials and field are readily available, as is occupation of employment. Gender, immigration status, and other factors are also associated with average differences in labour market outcomes. Therefore, before investigating whether or not a shortage or surplus of specialized STEM skills currently exists in Canada, the Panel looked first at the composition of STEM graduates, and how they differ from graduates in other fields in general.

STEM graduates in Canada are mostly men (72%), whereas a majority of non-STEM graduates are women (56%; see Figure 3.3 and Appendix B). A larger proportion of STEM graduates are immigrants (39%), compared with other fields (23% immigrants), especially at higher levels of education. Roughly half (50%) of STEM graduates at the bachelor's level and above are immigrants. For these figures, immigrants include those not born in Canada, regardless of where they were educated (see Appendix B for more details on these differences, and Chapter 6 for a discussion of representation of different groups in STEM fields).



Data Source: StatCan (2013i) and Panel calculations

Figure 3.3

Proportion of Women and Immigrants, for STEM and Non-STEM Graduates in Canada, 2011

For each group (women and immigrants), the bars show the proportion of each population (STEM graduates, non-STEM graduates, and Canadian adults aged 15 or older) that identifies as a group member. These include those who are employed, unemployed, and not in the labour force. STEM graduates are mostly men, whereas non-STEM graduates are mostly women. A larger proportion of STEM graduates are immigrants, compared with non-STEM graduates and Canadian adults overall.

These differences are important because women and immigrants tend to have lower incomes and poorer economic outcomes than men and Canadian-born workers overall (Drummond & Fong, 2010). As a result, aggregate differences in labour market indices between STEM and non-STEM graduates of similar education levels could be driven by large, underlying compositional differences, rather than real differences between fields of education. Labour market indices presented later in this chapter are therefore broken down by gender or immigration status, to verify that differences between STEM and non-STEM graduates are consistent across these groups, despite systematic differences between men and women or between immigrants and Canadian-born graduates.

3.2 LABOUR MARKET OUTCOMES OF STEM GRADUATES: SHORTAGE OR SURPLUS?

Canada leads the OECD in the proportion of the population with a post-secondary education (ISCED levels 5 and 6, including college and university certificates, diplomas, and degrees), which is one among many factors that contribute to an overall strength in science and technology research, as determined by an expert panel (CCA, 2012a). But how does this strength in science and technology translate into STEM skills in Canada's labour force?

An imbalance between supply and demand for workers with particular skills is inferred by economists based on a suite of labour market indicators. For example, a shortage of STEM skills would imply that demand exceeded the available supply of workers with these skills, meaning that this subset of the workforce would be expected to exhibit some or all of the following:

- high vacancy rates for jobs requiring these skills, and vacancies that remain open for long periods of time (these data are not available in sufficient detail to distinguish STEM graduates in Canada; see Section 3.1);
- low unemployment rates;
- high employment rates;
- rising wages;
- high rates of job matching, (i.e., most STEM graduates would be working in related fields, or occupations where STEM skills are needed); and
- increasing hiring of workers from non-traditional sources, (e.g., those with lower credentials, different educational backgrounds, temporary foreign workers).

(Cohen & Zaidi, 2002; Richardson, 2007; Plesca & Summerfield, 2014)

If the supply of workers with a skill *exceeds* demand, there would be a surplus of such workers, and they would be expected to show inverse patterns in the data (e.g., declining wages, increasing unemployment).

Various investigators have focused on annual wage growth or annual changes in unemployment rates as the basis for measuring occupational shortage (e.g., Cohen & Zaidi, 2002). While such measures may indicate short-term problems, data over a longer period will reveal whether the problem is quickly addressed by the market — a policy response may only be required if problems persist, suggesting a structural problem with the labour market. In many cases, market forces will address short-term imbalances and a concerted policy response may not be needed. For that reason, the Panel's analysis and conclusion are based on longer-term patterns.

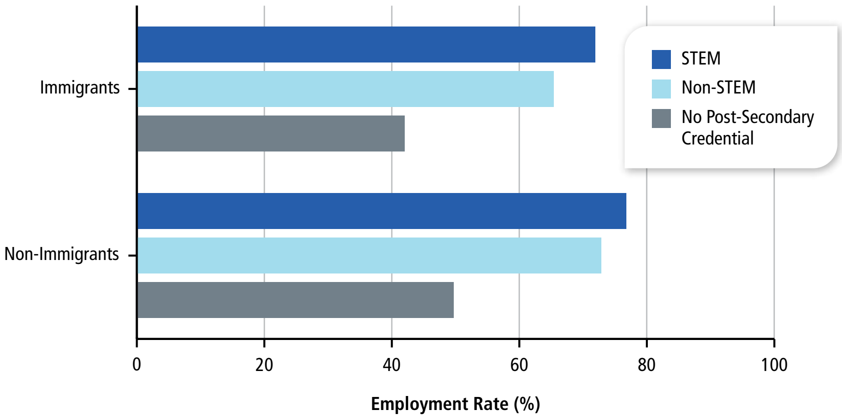
Although there is no standard set of criteria that objectively indicates a labour shortage, more signals that are consistent with a shortage or surplus tend to increase confidence that an imbalance is real (Cohen & Zaidi, 2002; Boswell *et al.*, 2004; Richardson, 2007). For example, the Canadian Occupational Projection System (COPS) assesses imbalances in occupational groups based on a number of these indicators, such as wage growth, changes in unemployment rate, employment growth, and others (ESDC, 2014c) (see Section 4.2).

Firms and workers can respond to labour market imbalances in many other ways. Both jobs and workers may physically move in response to shortages, firms may offer compensation other than wages, rely more on temporary workers, or workers may be asked to work more overtime (Richardson, 2007; Fang, 2009). Although data on job and worker mobility are sparse for Canada, immigration and emigration at the national level are explored in Chapter 7 in the context of the global market for STEM skills. A full and detailed analysis of indicators of over- and underemployment would be of great value to assessing the relative imbalance of STEM and non-STEM skills in the Canadian labour market. Such an analysis was not available to the Panel at the time of writing this report, representing a significant knowledge gap. Nevertheless, this section and Section 3.3 examine the indicators listed above, where data are available, and summarize the Panel's findings on apparent imbalances and mismatches of workers with STEM skills in Canada.

Many authors distinguish between an "aggregate shortage" and a "mismatch." An aggregate shortage implies full employment and overall difficulty in finding workers to fill positions across regions and economic sectors. A mismatch occurs when unemployment coexists with job vacancies because the vacancies do not match the location, skills, or preferences of unemployed workers, or a lack of information prevents employers from finding qualified workers and vice versa (Boswell *et al.*, 2004; Plesca & Summerfield, 2014). Most agree that there is no aggregate shortage (McDaniel *et al.*, 2014; Plesca & Summerfield, 2014), but that small-scale or temporary mismatches are possible (see also Gingras & Roy, 2000).

3.2.1 Employment, Unemployment, and Underemployment of STEM Graduates

To determine whether or not a shortage or surplus of STEM-skilled workers exists in Canada, the Panel first investigated the employment rates, unemployment rates, and potential underemployment of STEM graduates. Although employment rates are generally higher, and unemployment rates marginally lower, for STEM graduates, the differences between fields are larger among immigrants (see Figure 3.4, Table 3.2). On the other hand, women with a degree in a STEM field at the undergraduate level or above generally experience higher rates of unemployment than non-STEM degree-holders unless their degree is in a technology field (see Table 3.2).



Data Source: StatCan (2013i) and Panel calculations

Figure 3.4

Employment Rates of Immigrants and Non-Immigrants in Canada, by STEM Group, 2011

These data include all Canadians aged 15 or older; STEM and non-STEM groups include all levels of post-secondary education, including trade certificates, apprenticeships, college diplomas, undergraduate degrees, master's degrees, and earned doctorates. Both immigrants and non-immigrants with STEM degrees show higher employment rates than their counterparts with non-STEM degrees. Immigrants overall face lower employment, but appear to fare better if they have a STEM degree.

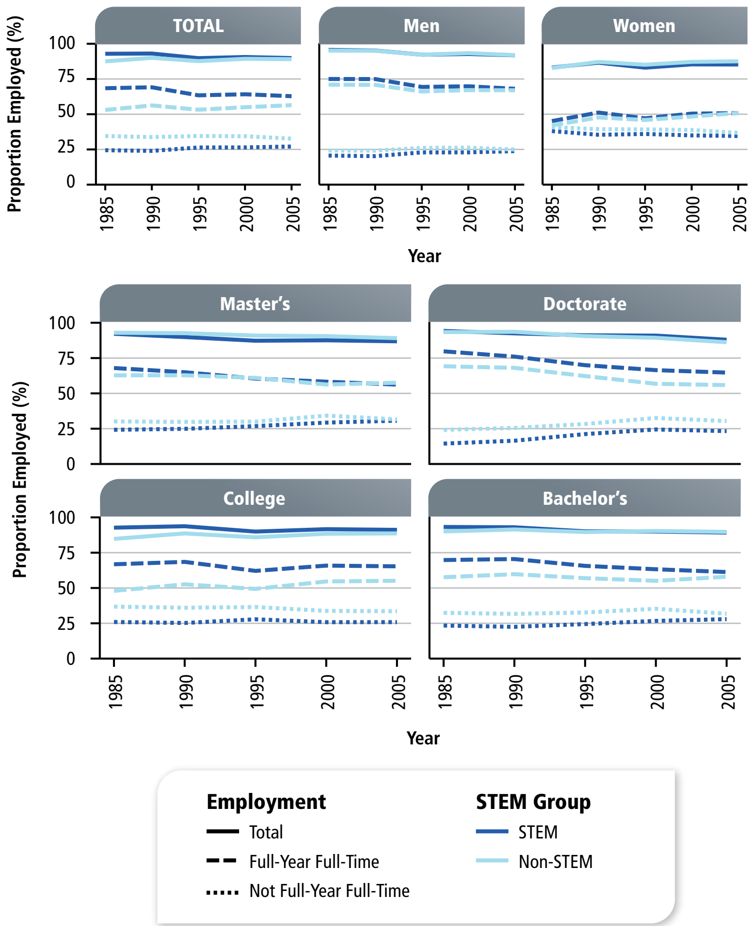
Table 3.2

Labour Market Outcomes of Degree-Holders in Canada Aged 25 to 34, by Gender and STEM Field, 2011

	Total	Women	Men
	(%)	(%)	(%)
Unemployment			
Total STEM	5.5	7.0	4.7
Science	6.2	6.6	5.8
Technology	5.1	3.4	6.7
Engineering	4.9	7.1	4.3
Mathematics and Computer Sciences	5.4	8.5	4.2
Non-STEM	5.6	5.7	5.5
	(%)	(%)	(%)
Skill Mismatch			
Total STEM	14.3	18.3	11.8
Science	18.0	18.9	16.8
Technology	22.2	20.5	23.5
Engineering	10.6	13.5	9.8
Mathematics and Computer Sciences	13.6	22.4	10.1
Non-STEM	19.7	18.5	22.2
	($)	($)	($)
Median Wages and Salaries			
Total STEM	59,300	53,200	62,300
Science	51,700	49,100	55,300
Technology	51,700	49,700	54,600
Engineering	65,200	61,100	66,300
Mathematics and Computer Sciences	59,300	54,900	60,800
Non-STEM	52,200	50,200	56,000

Reproduced with permission from Hango (2013)

Degree-holders in this table includes those with an undergraduate degree and above. *Skill mismatch* includes the percentage of persons working in occupations requiring a high school education or less. This includes persons who were employed during the NHS reference week, or weren't employed but last worked in 2010 or 2011. *Median wages and salaries* refers to gross wages and salaries before deduction, employees working full-year, full-time in 2010.



Data Source: StatCan (2014k)

Figure 3.5

Employment Rates of STEM Graduates in Canada, by Gender and Level of Education, Aged 25 to 54, 1985–2005

The data include all non-self-employed individuals aged 25 to 54 in the reference year who hold a college diploma, bachelor's degree, master's degree, or doctorate (law graduates excluded). Apparent differences in employment rates between fields ("TOTAL" panel, top-left) appear to be due to differences in gender composition: the lower rate of full-year full-time employment among non-STEM graduates appears to be driven by overall lower rates of full-year full-time employment among women, who make up most non-STEM graduates, but are a minority of STEM graduates. There are few overall differences in employment rates between STEM and non-STEM graduates, after accounting for gender and level of education. At the master's level, however, non-STEM graduates experienced slightly higher employment rates over this time period. STEM graduates at the college level experienced slightly higher employment rates than non-STEM graduates at the same level.

Data from harmonized census files show few overall differences between STEM and non-STEM graduates in employment rates from 1985 to 2005 in Canada, after taking into account differences between women and men, and among levels of education (see Figure 3.5). Apparent differences in overall employment rates between STEM and non-STEM graduates can be accounted for by differences in gender composition between these two groups: women experience overall lower levels of employment, including full-year full-time employment, and make up a majority of non-STEM graduates, but a minority of STEM graduates. Therefore, an apparent decline in employment rates of STEM graduates over time may be driven by a decline in employment rates of men, which account for a majority of STEM graduates. While there are obvious differences in employment rates between men and women, there are relatively small differences between STEM and non-STEM graduates within each gender group.

Master's graduates in STEM fields appear to have slightly lower employment rates than non-STEM graduates at the same level, while STEM graduates are slightly more likely to be employed than non-STEM graduates at the college level. Both men and women doctorates in STEM fields are more likely to be employed full-time than non-STEM doctorates: at other levels of education, differences in full-time employment between fields are driven largely by gender differences, as above (detailed data are not shown). These long-term trends do not suggest that STEM graduates are in any greater imbalance than non-STEM graduates at the national level. In fact, differences between STEM and non-STEM graduates declined from 1985 to 2005, along with an overall decline in employment rates.

STEM degree-holders (with an undergraduate degree or above) are less likely to be underemployed, with a smaller proportion finding employment that does not require a post-secondary education, except for those with a degree in a technology field (Table 3.2). Rates of employment, unemployment, and underemployment of STEM graduates therefore show no signs of a persistent, long-term imbalance at the national level. Rates of employment show larger differences between sub-fields of study, levels of education, genders, and immigrant statuses, than between STEM and non-STEM groups on average (see also Appendix C).

3.2.2 Earnings of STEM and Non-STEM Graduates

Chapter 2 discussed differences in short-term and lifelong earnings of STEM graduates, workers, and their non-STEM counterparts. While this comparison suggests that some STEM graduates have higher average earnings than graduates from other fields, historical trends can tell us how consistent these differences are. Wages for graduates in a field of study rising faster than those of other fields over several years can also be a sign of a structural shortage of skills taught in that field.

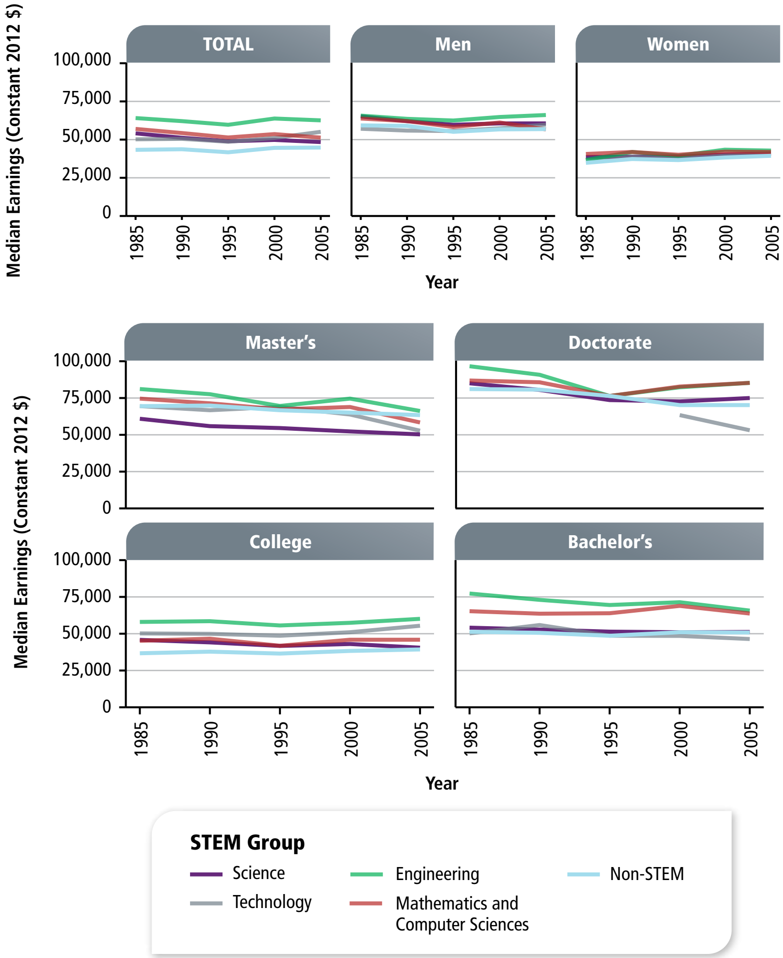
STEM degree-holders earned more on average than graduates in other fields in 2011, although this was driven primarily by high wages for graduates with a degree in engineering, as well as in mathematics and computer sciences (Table 3.2). On the other hand, median wages for degree-holders in science and technology fields were similar to those in non-STEM fields in the same year. These patterns are similar for both men and women. However, differences between fields are larger for men, and women tend to be concentrated in fields associated with lower wages, such as science and technology (Hango, 2013).

This is consistent with the historical data shown in Figure 3.6: apparent overall patterns in median earnings can be accounted for by differences in gender composition and a persistent earnings gap between men and women. While engineering graduates tend to earn more than other STEM fields, women with a degree or certificate in mathematics and computer sciences may earn almost as much as women engineers. Again, because women earn less than men across all fields and are a majority of non-STEM graduates, the overall earnings of non-STEM graduates appear very low compared with STEM fields, whereas differences between fields are smaller when compared within gender groups.

Historical data show that differences in earnings among fields of education have been relatively stable over time, but do vary by education level and gender. Graduates in engineering, mathematics, and computer sciences have generally enjoyed higher earnings than non-STEM graduates, while earnings of science graduates have often been comparable to non-STEM graduates, and sometimes lower (see Figures 3.6 and 3.7).

Median earnings spiked in 2000 for graduates in engineering, mathematics, and computer sciences, at the bachelor's level and above, but declined in 2005, especially among men (Figure 3.6). This suggests that if there was a shortage of these skills around 2000, it was temporary, consistent with the burst of the dotcom bubble and reduction in demand for some of these skills around this time (Beaudry *et al.*, 2013).

At the master's level, non-STEM graduates have historically earned about as much as high-earning STEM graduates, while those with a master's degree in science have earned less than many with an undergraduate degree (see Figures 3.6 and 3.7). Doctoral graduates are a small group among both STEM and non-STEM graduates, and reliable data on earnings are not always available for some fields. In recent years, doctoral graduates have tended to earn more than other levels of education, with only small differences between STEM and non-STEM fields (Figure 3.7).

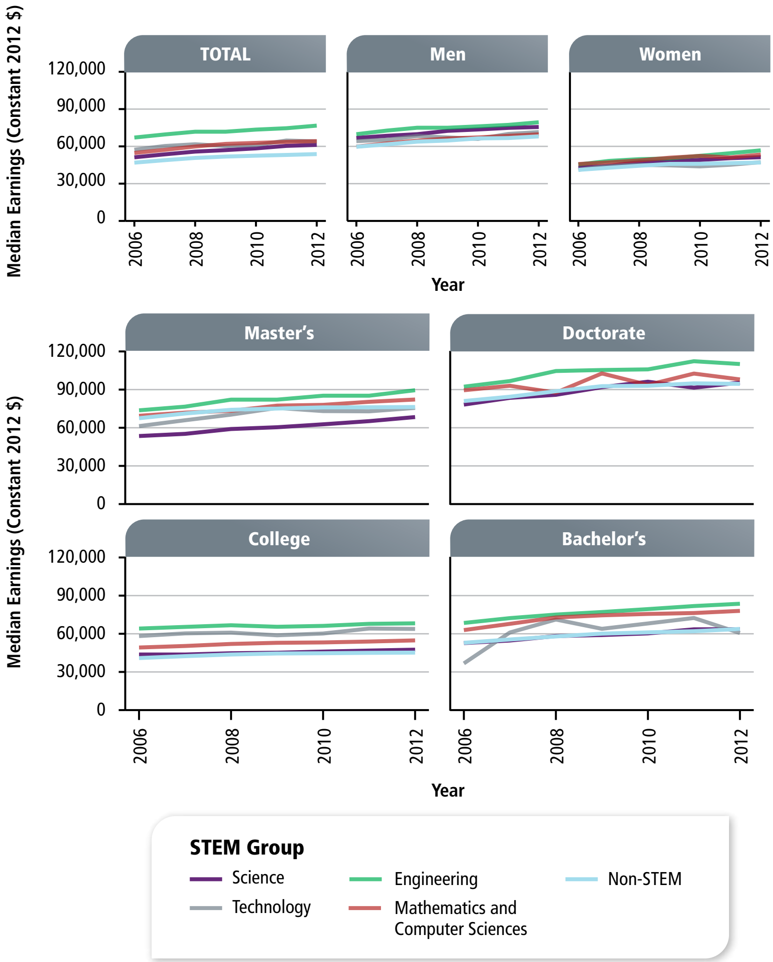


Data Source: StatCan (2014k)

Figure 3.6

Median Earnings of Graduates in Canada, by STEM Field, Gender, and Level of Education, Aged 25 to 54, 1985–2005

The data include all non-self-employed individuals aged 25 to 54 in the reference year, who hold a college diploma, bachelor's degree, master's degree, or doctorate, with earnings greater than zero (law graduates excluded). As seen with employment rates, apparent lower earnings for non-STEM graduates may be driven by gender differences between STEM and non-STEM graduates: women earn less overall than men, and make up a majority of non-STEM graduates, and a minority of STEM graduates. Median earnings of some STEM graduates (in engineering, mathematics, and computer sciences) increased temporarily around 2000, but declined again by 2005, which coincides with the technology bubble bursting around this same time period.



Data Source: StatCan (2014i)

Figure 3.7

Median Earnings of a Cohort of STEM Graduates in Canada, by Gender and Level of Education, Aged 25 to 54 in 2006, 2006–2012

The data include all non self-employed individuals in the tax year in question (2006 to 2012), who were age 25 to 54 and held a college diploma, bachelor's degree, master's degree or doctorate in 2006 (law graduates excluded). Since tax records are from the same sample of individuals from the 2006 Census, these trends reflect changes in earnings of a single cohort, rather than a representative sample of each year. At the college and bachelor's level, science graduates have earned similar levels as their non-STEM counterparts, while graduates in engineering, mathematics, and computer sciences have experienced higher median earnings. Master's graduates in non-STEM fields, however, received similar earnings to higher-paid graduates of STEM fields, with science graduates earning the least. Doctoral graduates in both science and non-STEM fields earned similar levels in recent years.

Although there are some persistent differences in earnings levels between some STEM and non-STEM graduates, these differences depend a lot on sub-field of STEM, level of education, and gender. Furthermore, these earnings are not growing faster for STEM graduates than non-STEM graduates over the long term. The Panel did find evidence of short term shortages for some groups — such as mathematics, computer sciences, and engineering graduates in 2000 — but these were temporary. Long term trends in earnings therefore suggest no persistent national-level imbalance in the supply and demand for STEM skills.

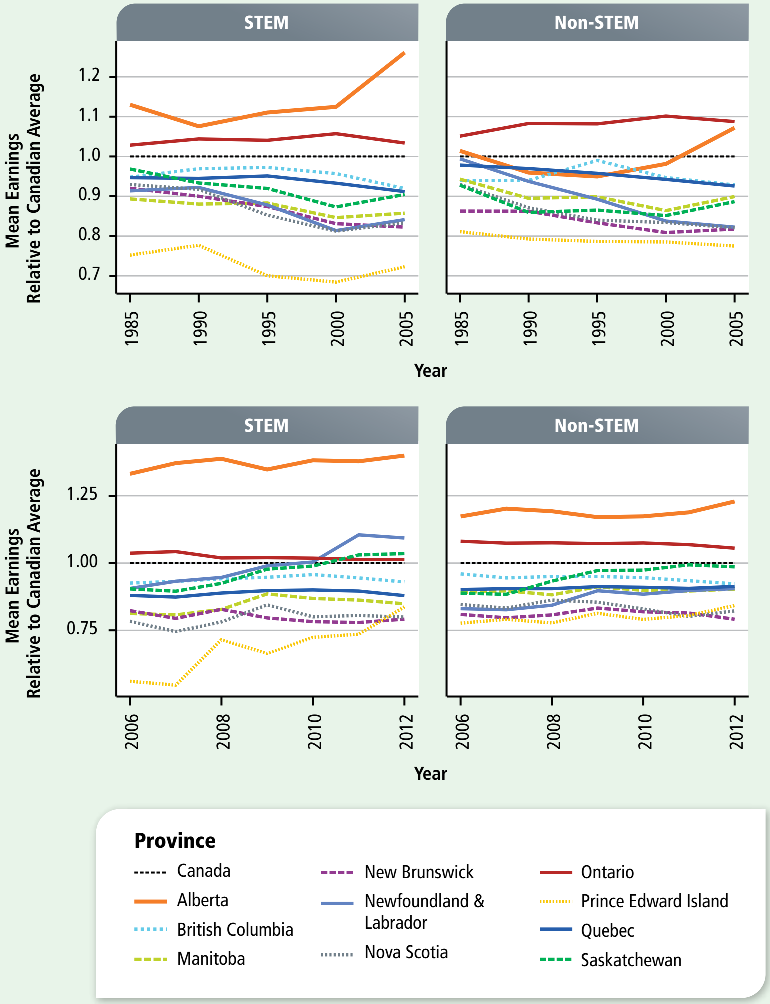
3.2.3 STEM Graduates in No Greater Shortage than Non-STEM Graduates

The approach used by the Panel to identify shortages consists of examining whether STEM graduates have exhibited above average increases in wages and employment over a sustained period of several years, relative to other fields. STEM graduates would be considered in shortage only if such features are present. For example, if STEM graduates only exhibit a high real wage or rate of employment, but do not exhibit sustained increases in real wages or employment rates, we do not interpret such a situation as reflecting a shortage. Similarly, if there is high employment growth, but wages are stable, again this is not interpreted as reflecting a shortage.

Based on this approach, the Panel found no evidence indicating a persistent national imbalance in most STEM fields. National aggregate trends can mask regional or sectoral imbalances, however, with excess demand for, or supply of, skilled labour existing in some regions and sectors (Lefebvre *et al.*, 2012). Some regional mismatches appear to exist, but in most cases they are not exclusive to STEM fields (see Box 3.1).

Graduates in engineering, mathematics, and computer sciences continue to enjoy higher earnings, lower unemployment, and lower underemployment than other STEM fields on average, but some non-STEM fields, such as medical and business fields, show similar patterns in labour market outcomes (see Appendix C). Differences between more detailed fields of study are larger than the differences between STEM and non-STEM graduates overall. Field of study continues to affect graduates' labour market outcomes (Stark, 2007), but STEM fields are not wholly different from non-STEM fields for most labour market indicators or trends over time.

Box 3.1
Regional Imbalances in STEM versus Non-STEM Graduates



Data Source: StatCan (2014i, 2014k)

Figure 3.8

Earnings of STEM and Non-STEM Graduates by Canadian Province, Aged 25 to 54, 1985–2005 and 2006–2012

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Earnings are plotted as the ratio of mean earnings in each province to the median earnings across Canada as a whole. For 1985–2005 (upper panel), all individuals aged 25 to 54 in each year are included; the 2006–2012 data represent a cohort of individuals aged 25 to 54 in 2006. Although there is considerable variation in mean earnings of STEM and non-STEM graduates among provinces, there is no consistent difference between STEM and non-STEM graduates or a marked increase in earnings of STEM relative to non-STEM graduates in recent years. From 2006 to 2012, earnings relative to the Canadian mean were highest in Alberta for both STEM and non-STEM graduates, indicating a fast-growing economy rather than a greater shortage of one set of graduates or another.

There are considerable differences in relative earnings among provinces, with greater variation among STEM graduates than non-STEM graduates (Figure 3.8). Earnings have increased faster in Alberta than in other provinces, suggesting growing demand for skills and difficulty finding an adequate supply. Nevertheless, these signals are not unique to STEM graduates and apply across fields of education and occupations. Such a tight labour market is consistent with a fast-growing economy, rather than a shortage of particular skills. Although some skills appear to be in greater demand than others, notably those associated with the resource sector (mining and petroleum), these include both highly cognitive skills, including STEM skills, as well as low-skilled labour and non-STEM graduates (see Polgreen & Silos, 2009; Morissette *et al.*, 2013).

In the context of declining birth rates and an aging population, there are concerns of a looming shortage of high-skilled labour. Research indicates that workers are staying in the labour force longer, however, contributing to continued labour force growth until 2031 (McDaniel *et al.*, 2014). In some sectors, however, replacement demand for retiring workers can lead to a mismatch of skill levels. For example, there is a growing shortage of specialized engineers with over 10 years of experience, coexisting with an abundance of recent engineering graduates who lack the experience to fill available positions (PEA, 2012) (see also Box 6.1). In this case, it is not a *skills* mismatch, but rather an *experience* mismatch that leads to higher unemployment and underemployment among younger engineers.

The Panel's findings are consistent with McDaniel *et al.* (2014), who conclude that while Canada does not have a national labour shortage (and is unlikely to have one in the foreseeable future), imbalances and skill mismatches are present in some sectors and regions. Due to fluctuating labour circumstances in a "dynamic economy," experts note that short-term regional and sectoral mismatches are a common aspect of the labour market cycle (Gingras & Roy, 2000). In many cases, market forces will address such mismatches and hence a concerted policy response may not be required.

The findings in this section have focused on individuals in Canada whose highest degree is in a STEM field. Although labour market outcomes from this perspective are relevant to those choosing a field of education for study, some of the variation may be due to the occupations in which these graduates are working. Where are STEM graduates working, and which occupations require high levels of STEM education? These questions represent the final lines of the Panel's investigation into whether or not Canada is currently experiencing a shortage of STEM-skilled labour.

3.3 STEM EDUCATION AND OCCUPATION MATCHING

Data sets such as O*NET in the United States allow for analyses of skills content of occupations and workers beyond educational background (Carnevale *et al.*, 2011; Rothwell, 2013). In the absence of such resources, STEM occupations may be defined by the educational content of their workers. For example, the U.K. Commission for Employment and Skills defines STEM occupations using a combination of the proportion of workers in each occupation with a post-secondary credential in a STEM field (*density*), and the proportion of STEM graduates working in each occupation (*proportion*) (UKCES, 2011; Bosworth *et al.*, 2013). If both minimum criteria are used to define STEM occupations, however, some occupational groups that employ relatively few people, but most of whom are STEM graduates, might not be captured.

The Panel defines a *STEM-intensive occupation* as one where at least 50% of workers in the occupation have their highest level of education in a STEM field (as defined in Section 1.2). This approach is limited by the classification scheme for occupations used, and some STEM-intensive workers in certain sectors or occupational groups may not be captured by these criteria. Nevertheless, this approach provides an overall picture of the distribution of STEM graduates in the labour force.

Table 3.3

STEM-Intensive Occupations in Canada, 2011

NOC Code	Occupation	STEM Density (%)	STEM Proportions			
			STEM Proportion Overall (%)	Men (%)	Women (%)	Immigrants (%)
213	Civil, mechanical, electrical and chemical engineers	88.5	**6.9**	8.1	3.6	7.2
211	Physical science professionals	85.9	**1.5**	1.4	1.9	1.6
214	Other engineers	81.7	**3.1**	3.7	1.6	3.5
216	Mathematicians, statisticians and actuaries	76.1	0.5	0.3	0.8	0.4
212	Life science professionals	68.0	1.1	0.7	2.0	0.7
217	Computer and information systems professionals	67.8	**11.6**	12.9	8.4	14.0
221	Technical occupations in physical sciences	60.5	1.2	0.9	1.9	1.0
021	Managers in engineering, architecture, science and information systems	60.1	**2.6**	3.0	1.7	2.2
228	Technical occupations in computer and information systems	59.2	**4.1**	4.8	2.2	3.7
224	Technical occupations in electronics and electrical engineering	57.5	**2.9**	3.8	0.7	2.2
223	Technical occupations in civil, mechanical and industrial engineering	52.8	**2.0**	2.4	0.9	1.6
225	Technical occupations in architecture, drafting, surveying, geomatics and meteorology	50.5	**1.5**	1.6	1.3	1.1
	Total (% of employed STEM graduates working in a STEM-intensive occupation)		38.9	43.6	26.9	39.1

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NOC Code	Occupation	STEM Density (%)	STEM Proportions			
			STEM Proportion Overall (%)	Men (%)	Women (%)	Immigrants (%)
401	University professors and post-secondary assistants	43.2	**2.5**	2.1	3.5	3.0
321	Medical technologists and technicians (except dental health)	28.3	**2.0**	0.6	5.6	1.7
122	Administrative and regulatory occupations	8.4	**1.9**	1.2	3.8	1.8
724	Electrical trades and electrical power line and telecommunications workers	20.8	**1.7**	2.3	0.2	1.4
416	Policy and program researchers, consultants and officers	17.6	**1.7**	1.2	3.1	1.4
642	Retail salespersons	7.6	**1.6**	1.4	2.1	1.9
403	Secondary and elementary school teachers and educational counsellors	5.6	**1.5**	0.9	3.0	1.2
001	Legislators and senior management	17.2	**1.4**	1.7	0.7	1.1

Data Source: StatCan (2014n) and Panel calculations

"STEM density" is the proportion of workers employed in the occupation whose highest level of education is in a STEM field. "STEM proportion" is the proportion of workers with a STEM credential employed in that occupation. **Bolded** values indicate occupations that collectively employ 50% of STEM credential-holders. STEM densities declined slightly with age (i.e., the proportion of workers aged 45 to 54 working in occupations with a STEM degree was slightly lower than among those aged 25 to 34), but the differences were smaller than between men and women. *Sample*: All individuals aged 25 to 54 in 2011 who reported an occupation. This table includes those with apprenticeships and trades certificates, college certificates and diplomas, and university degrees below the bachelor's level and above, in a STEM field. STEM-intensive occupations are those where at least 50% of workers in the occupation have a post-secondary credential in a STEM field: these are above the "Total" row in the table. Most employed STEM graduates (61%) do not work in a STEM-intensive occupation; even more so for women (73%).

Using data from the 2011 NHS, 12 STEM-intensive occupations met the criteria, out of 140 3-digit National Occupational Classification (NOC) codes. Not surprisingly, these include a range of technical occupations, engineering, science professionals, and managers in STEM fields (see Table 3.3).

The Panel also examined occupations that employ the most STEM graduates (based on the STEM proportion), which reveal where STEM graduates tend to work, and thus which occupations are important destinations for STEM graduates in the labour market. There is some overlap between STEM-intensive occupations and those that employ the most STEM graduates. But a majority of STEM graduates find employment in other occupations, which also employ a majority of people without a post-secondary STEM degree (including those whose highest credential is in a non-STEM field, and those with no post-secondary education). STEM-intensive occupations only employ 39% of employed STEM graduates, meaning that 61% of them are working in other occupations, as shown in Table 3.3 (Panel calculations using StatCan, 2014n).

The proportion of employed STEM graduates working in STEM-intensive occupations is even lower for women: 27%. Not only are women under-represented among STEM graduates (Figure 3.3), women STEM graduates are also under-represented in STEM-intensive occupations (Table 3.3).

COPS has assessed recent imbalances as part of its forecasting procedure. Its 2013 analyses found two of the STEM-intensive occupational groups listed in Table 3.3 in shortage (NOC codes 212 and 213: (life science professionals; and civil, mechanical, electrical, and chemical engineers), with the rest being relatively balanced (ESDC, 2014c) (see Table 4.1). Shortages were also found in medical occupations, trades, and resource occupations, while many low-skill occupations and those involving routine tasks were found to be in surplus. Therefore, imbalances or mismatches may exist in some areas, but STEM workers as a group appear to be in no greater imbalance than other occupations. These results are generally consistent with the Panel's analysis by field of study.

Although the STEM-intensive occupations listed in Table 3.3 tend to rely on STEM graduates, and are where many STEM graduates tend to work, Canadians with a STEM education also work in a wide variety of occupations. A growing proportion of non-STEM graduates working in a STEM-intensive occupation would be consistent with a shortage of STEM workers, indicating that employers are using less restrictive criteria to find workers. Even in the most STEM-intensive occupational groups, at least 10 to 20% of those employed do not have a STEM post-secondary credential. On the other hand, most occupations employ at least a few STEM graduates, and most STEM graduates work outside of STEM-intensive occupations, as defined here.

Education in a STEM field may not be the only qualification for working in STEM-intensive occupations. Many employers prioritize complementary skills — such as communication, problem solving, leadership, and interpersonal skills — in prospective employees, and these skills are not discipline-specific (see Section 4.3.3). Some STEM workers do not have a STEM degree, while most STEM graduates do not work in STEM-intensive occupations. The Panel concluded that this apparent mismatch may reflect the transferable nature of STEM skills, their utility in many sectors, and the many sources of STEM skills. As discussed in Section 2.1, educational background does not capture the full range of a worker's skills, although it is an easily observable portion of a worker's skill set. Workers in occupations that are not STEM-intensive may still be using their STEM skills and other skills productively, while many employers value workers with complementary skills, in addition to STEM skills. The range of occupations employing STEM graduates, and their relatively low levels of underemployment, therefore suggests that having STEM skills offers workers more employment options, particularly if combined with the complementary skills sought by employers.

3.3.1 Why Most STEM Graduates Work in Non-STEM Jobs

In the United States, Lowell and Salzman (2007) point out that there are more than three times as many university graduates in science and engineering each year than there are available job openings in those fields. The U.S. Census Bureau reports that only one-quarter of STEM graduates are employed in a STEM occupation (Landivar, 2013). These numbers and those in Table 3.3 appear to indicate an oversupply of STEM-trained workers in the United States and Canada. Nevertheless, there are several reasons why people who graduate from a STEM field do not go on to work in a STEM occupation, and it is not always due to a lack of available jobs in their field.

Career progression is not always a straightforward, linear path. Those who graduate with a STEM degree may discover that they do not enjoy STEM work, develop other interests, or not be able to find a suitable STEM vacancy. Others may always work in a STEM occupation. Some may leave the workforce entirely to care for family members. Others may engage in STEM-related work for a while before advancing to fill management positions, which may not be classified as STEM jobs but require STEM skills. There is no single pathway for workers with STEM skills flowing from certain education programs. Instead, a range of pathways can link education, training, and experience to employment opportunities.

For employed Canadians in 2006, 59% of graduates in physical and life sciences and technologies, 59% of graduates in architecture and engineering, and 51% of graduates in mathematics, computer, and information sciences had a job “closely related” to their field of study (Yuen, 2010). In contrast, 23%, 24%, and 21% of graduates in the above fields of study, respectively, were working in jobs that were “not-at-all related.” As a point of reference, 68% of those with a post-graduate university degree (above the bachelor’s level) had jobs that were closely related and only 12% worked in unrelated jobs. This mismatch between education and occupation can lead to lower earnings than those working in a job unrelated to their field of study. For example, people who studied engineering or architecture but worked in an unrelated occupation only earned 75% as much per hour as those with jobs related to their field of study. Robst (2007), however, finds that individuals in the United States who choose to work in a different field than their education because of pay, working conditions, or interest, experienced higher earnings, while those who switch because of a lack of jobs tend to earn less than those who work in a related field.

This tendency to take jobs outside of their field of study does not necessarily reflect an inability of STEM workers to find STEM jobs. STEM graduates appear to be no worse off in finding employment and are more likely to find jobs that make use of their level of education (see Table 3.2), even in a field that is not closely related. Using data from the U.S. 2006 Scientists and Engineers Statistical Data System, Carnevale *et al.* (2011) find that only 14% of those with the highest degree in STEM working in non-STEM fields in the United States reported doing so because they could not find a suitable job in their field. Only 11% of unemployed individuals whose highest degree was in a STEM field cited being unable to find a suitable job in their field as a reason for not working. As with data on earnings and employment, reasons for working in unrelated fields might vary by field. For example, Salzman *et al.* (2013) find that one year after graduation, 32% of computer and information technology degree-holders, and 30% of engineering degree-holders in the United States cited not being able to find a job in their field as a reason for working in a different one. Reasons for Canadian STEM graduates working in other fields have not been studied.

Rather than a lack of jobs, most STEM graduates in the United States choose to work in other fields because of higher earnings or other personal preferences. These choices may benefit the individual, but may represent lost productivity at the aggregate level: if STEM workers in STEM occupations are able to boost the productivity and wages of other workers (recall Section 2.4), then a decision to work in a non-STEM job would also prevent such spillover benefits from being realized, provided no other workers with STEM skills are available to fill that role. In economic terms, the positive spillover effects of STEM workers ("externalities") are not taken into account by the workers themselves, leading to individual decisions that are not optimal (not efficient) for society.

Many STEM skills are applicable to many fields, which is an increasingly valuable characteristic in the labour market. A recent report on the skills necessary to succeed in the 21st century notes the importance of critical thinking and problem-solving skills and possessing multidisciplinary knowledge (Pellegrino, 2013). Critical thinking and problem solving are fundamental skills for STEM, and cultivated in STEM and other fields; although these skills are not exclusive to STEM fields, graduates of STEM programs are expected to have these and other skills that are transferable and applicable to other areas of work. Langdon *et al.* (2011) estimate an 11% regression-adjusted earnings premium of STEM degree-holders in any field of employment (including STEM and non-STEM occupations) in the United States, using data from the 2009 American Community Survey.

In a world where machines are increasingly able to take the place of workers in performing routine tasks, the ability to deal with non-routine tasks is increasingly important for earnings and employment (Autor *et al.*, 2006; Frey & Osborne, 2013) (discussed further in Chapter 4). STEM training provides workers with logical approaches to handling a broad range of problems, which are transferable to a wide variety of occupational settings. Carnevale *et al.* (2011) find that mathematical skills and critical thinking skills are considered at least "important" in the vast majority of occupations in the United States. Koedel and Tyhurst (2012) performed an experiment in which resumes were sent to a group of employers, randomly varying the claimed level of mathematical skills of the applicants. They found that employers were more likely to respond favourably to applicants with greater mathematical skills even in non-mathematical fields, such as sales. Of course, it is unclear if employers actually value the mathematical skills or if they are a signal for other characteristics, such as general intelligence. The "diversion" of STEM graduates to non-STEM jobs may therefore reflect the transferable nature of STEM skills, rather than a surplus (Carnevale *et al.*, 2011).

Finally, a significant number of people who end up working in STEM fields do not possess STEM degrees. Carnevale *et al.* (2011) point out that 6% of those who did not graduate with a STEM major[12] in the United States in 1988 ended up working in STEM occupations later in life. Even in the most STEM-intensive occupations in Canada, there are a few workers whose highest

12 This includes both those who graduated with a non-STEM degree and those who did not graduate.

degree is not in a STEM field or who lack a post-secondary credential altogether (see Table 3.3). This suggests that at least some STEM skills can be learned outside of such programs.

3.4 CONCLUSION

Available data suggest that roughly 1 in 10 Canadians have a post-secondary credential in a STEM field, of which 39% are immigrants and 28% are women. The proportion of post-secondary graduates in STEM fields in Canada is higher than the OECD average, but lower than in many peer countries. Although a relatively low proportion of Canada's population has an earned doctorate, most of them are in STEM fields.

STEM graduates in some fields experience higher employment rates and lower unemployment rates than their counterparts in non-STEM fields. Earnings data show variation by gender, field of education, and education level. Although spikes in historical wages have been consistent with a temporary increase in demand, there are no recent indications that STEM graduates are in greater shortage or surplus than non-STEM graduates. Most employed STEM graduates do not work in STEM-intensive occupations, and even the most STEM-intensive occupations employ some workers whose highest level of education is not in a STEM field. The level of "diversion" of STEM graduates to non-STEM jobs may indicate the flexible and transferable nature of STEM skills rather than a surplus — STEM education appears to provide workers with more options in both STEM and non-STEM work.

The available evidence suggests no national imbalances in workers with post-secondary education in a STEM field, and a well-functioning labour market, where individuals are choosing fields of study and occupations based on market signals and personal preferences. Nevertheless, this should not be taken to mean that there are no labour market mismatches at the regional level. The Panel acknowledges that a national analysis may not capture regional mismatches, but data at finer spatial scales were not of sufficient quality to draw general conclusions. Furthermore, the changing nature of work, increasing use of technology, and globalization all have implications for the future demand of STEM skills in Canada and around the world.

4

Projecting Future Demand for STEM Skills in Canada

4 Projecting Future Demand for STEM Skills in Canada

Key Findings

Long-term labour market demands are difficult to predict. It is especially challenging to estimate future demand for practical, advanced, and otherwise specialized STEM skills. A range of external forces influence the economy, including constant changes in technology that can profoundly alter the nature of work.

Most future projections are inherently unreliable because they are based on the assumption that historical relationships will continue in the future. The accuracy of forecasts decreases with the length of the forecasting period and as projections are disaggregated by skill type, occupation, and region.

It is not possible to definitively determine the skills and knowledge that will be required for the jobs of the future. However, it is clear that STEM skills are central to a variety of education and job opportunities. They provide individuals with education and career options, which is a benefit given future labour market uncertainties.

Complementary skills, such as leadership, business acumen, creativity, and communication ability, may enhance STEM skills. In addition, such assets are transferable and consistently demanded by employers.

A focus on very narrowly specialized STEM skills development to meet short-term labour market requirements may have little relevance for meeting long-term skill requirements.

This chapter explores whether the current trends in labour market demand for STEM skills in Canada can be expected to continue or change in the future. First, the Panel looks at the evidence and historical data for technology trends and the implications for the demand for skills, including STEM skills, in the Canadian economy. Second, the Panel reviews national labour market projections from COPS (the federal government's central tool for projecting future labour supply and demand) and the limitations associated with these projections. Third, in the face of the uncertain impacts of technology trends on skill demands and the limitations of national labour projections, the Panel explores the evidence on what types of skills will be demanded by employers and be most essential for an unknowable future. The focus is on the complementary skills required to effectively work in a business environment and enhance practical and advanced STEM skills, and on the fundamental skills for STEM that give individuals the tools to respond to an ever changing and uncertain labour market.

4.1 TECHNOLOGY AND THE EVOLUTION OF WORK

Four global megatrends are expected to challenge the world over the coming decades: the rapid development of new ICT applications, an aging population, environmental degradation, and slowing growth in the United States (CCA, 2013c). In many ways, the basis for — and the solutions to — these major challenges is linked to technology. The rapid pace at which technological development is moving and the associated economic impacts mean that changes in work itself are both inevitable and important. Drawing on a strong body of U.S. research, this section examines shifting trends in technological change, which suggest that technological advances do not always increase the demand for skills. While the context may be different, U.S. examples can be informative to Canadians, especially considering Canada's role in an integrated North American economy.

Economics research has documented growth in the demand for skills,[13] accompanied by a reduction in demand for middle-skill routine occupations, in the decades leading up to 2000. This period of polarization in the U.S. labour market has been characterized by skill-biased technical change, as employment diverged into high-wage and low-wage jobs, at the expense of middle-skill jobs (Acemoglu, 2002; Card & DiNardo, 2002; Autor *et al.*, 2006; Cowen, 2011; Beaudry *et al.*, 2013; Brynjolfsson & McAfee, 2014). Middle-skill jobs are usually associated with routine tasks, such as administrative tasks that can be automated. Theories of skill-biased technical change posit that as computerization displaces workers in this middle category, the wage structure becomes "hollowed out," and the focus shifts to abstract tasks at the upper end of the wage spectrum and manual or service-related tasks at the lower end (Autor *et al.*, 2006; Autor & Dorn, 2013).[14] Both of these categories of tasks require skills that are not easily computerized (see Box 4.1). Such a model of technical change assumes that technology complements either high- or low-skill workers (Acemoglu & Autor, 2010).

13 The demand for cognitive tasks usually associated with high educational skill (Beaudry *et al.*, 2013).

14 Other factors that are understood to contribute to such polarization include globalization and deunionization (Katz & Autor, 1999).

Box 4.1
Labour, Technology, and Non-Routine Tasks

The increasing substitution of labour with technology (a form of capital) is thought to be responsible for simultaneously decreasing demand for some types of labour, while increasing demand for others. Many occupations previously thought to be immune to automation are increasingly being automated by ever-expanding capabilities of technology (e.g., algorithms for pattern recognition, and enhanced senses and dexterity of robots) (Frey & Osborne, 2013; Brynjolfsson & McAfee, 2014). Frey and Osborne (2013) estimate the probability of computerization for 702 occupations, finding around 47% of total U.S employment at "high risk" of computerization over the next decade or two (>70% probability). This includes "most workers in transportation and logistics occupations, together with the bulk of office and administrative support workers, and labour in production occupations" (Frey & Osborne, 2013). Even many jobs in service occupations appear to be highly susceptible to computerization: routine task-intensive occupations (e.g., clerical, administrative, and support positions), which are prone to automation, are contracting in the United States and across the European Union (Autor, 2013). Wages and educational attainment are found to decline rapidly with increasing probability of computerization (Frey & Osborne, 2013).

On the other hand, the jobs least likely to become computerized depend on complex perception and manipulation tasks, problem solving, creativity, or social intelligence (Frey & Osborne, 2013). Task-based studies of labour markets suggest that demand for routine tasks has been falling, while non-routine jobs have remained in demand, regardless of whether those tasks are cognitive or manual (two categories that are at opposite ends of the occupational skill distribution) (Autor *et al.*, 2006; Acemoglu & Autor, 2010). Non-routine cognitive or abstract tasks (including STEM skills, for example) require problem solving and creativity, and are typically held by workers with high levels of education and analytical capacity. These tasks can be complementary to technology because they generally draw on information. Non-routine manual tasks require situational adaptability, physical dexterity, and interpersonal interaction, and generally require little formal education (Autor & Dorn, 2013). Both of these categories of tasks are challenging to automate because of the level of adaptability required to respond to "unscripted interactions" which currently exceed the limits of machine-compenency (Acemoglu & Autor, 2010).

While the classical model outlined above operationalizes ideas about the skill bias of technical change, it does not fully explain some important historical patterns. The skill bias of technical change has changed over time and across countries; technological advances have not always increased the demand for skills (Acemoglu & Autor, 2010).

For example, Acemoglu (2002) explains how manufacturing technologies replaced skilled artisans in the early 1800s. By the 1900s, however, these technologies were generally complementary to skills (see also Acemoglu & Autor, 2010). Twentieth-century trends showed increasing demand for high-skilled workers, including those with STEM skills.[15] Data from about 2000 onwards, however, call the consistency of these trends into question, suggesting that skill-biased technical change can cause a boom and bust in the demand for cognitive tasks (Beaudry *et al.*, 2013). Ongoing work by Beaudry *et al.* (2013) suggests that although demand for cognitive skills (of which STEM skills are a subset) increased dramatically throughout the 1980s and 1990s, that demand appears to have waned, if not decreased, since about 2000. The decline in demand for cognitive skills affects low-skilled workers as well as high-skilled workers. As high-skilled workers begin to take on jobs usually accomplished by low-skilled workers, low-skilled workers are pushed to the downward periphery of the occupational structure, towards non-employment. In other words, as demand for higher skills declines, educated workers who would have formerly held high-skill jobs move downward into routine and service jobs.

It is unclear whether past trends in the relationship between technology and the labour market will continue to hold in the long run. While technology often leads to increased productivity, there is renewed debate around whether this will also tend to increase employment or if long-term structural technological unemployment is possible (Brynjolfsson & McAfee, 2014). Private employment sagged around 2000 in the United States, while productivity has continued to increase (Jared Bernstein, as cited in Brynjolfsson & McAfee, 2014). This, coupled with indications of decreasing demand for cognitive skills (Beaudry *et al.*, 2013), creates several uncertainties. Even some basic trends in technology use may not be as stable as once thought. After 40 years of substantial increases in information technology investment, including dramatic increases in the 1990s, recent U.S. data suggest that as a share of the gross national product (GNP), investment in information processing equipment and software, and computers and peripheral equipment, has actually declined since around 2000 (Beaudry *et al.*, 2013).

15 The belief that this process remains unchanged continues to be reflected in some economic literature (as explained by Beaudry *et al.*, 2013).

The only evidence of whether or to what extent such polarization has emerged in Canada is based on preliminary work from Green and Sand (2014). Overall, they argue that while wage and employment patterns in Canada resemble those in Europe and the United Kingdom, they do not align with the standard technological change model. Using census and Labour Force Survey data from 1971 to 2011, they find that polarization of employment occurred in the Canadian labour market in the 1980s and 1990s, with higher employment growth in high and low-paying occupations relative to the middle. Employment growth at the top end appears to have stalled since 2000. Data also reveal increases in wage inequality, but provincial variations suggest that while technology may be driving outcomes among those in middle and upper-skilled jobs, resource booms may be affecting those in lower-skilled occupations (Green & Sand, 2014).

There is also little evidence to suggest that Canada's economy is in the midst of a transition to a greater dependence on high-technology industries. High-technology exports account for a smaller share of total manufacturing exports in Canada than the OCED average, and Canadian high-technology exports as a share of world exports have been declining since 2000 (partially reflecting the increase in energy exports throughout the early 2000s) (CCA, 2013b). Likewise, business spending on R&D peaked in Canada in 2001 and has steadily declined in recent years. The current number of professional personnel engaged in R&D remains lower than it was in 2008 and has shown little sign of rebounding to pre-crisis levels (StatCan, 2014f). Despite a strong academic research sector, Canada's productivity problem persists (CCA, 2013c). This has been attributed to low levels of business innovation (CCA, 2013c). Unless the demand for advanced STEM skills increases, this trend is likely to continue.

While literature on technological change is revealing, much of it remains theoretical. Past trends can inform our expectations of future patterns, but precision regarding future STEM skill requirements is impossible. Ultimately, the overall impact of technology on labour markets depends on how new technologies are applied (Brynjolfsson & McAfee, 2014). As can be expected in the process of creative destruction and disruption associated with innovation,[16] new technologies or methods may replace certain jobs, products, and processes

16 Economist Joseph Schumpeter coined the term *creative destruction* in 1942. Accepted as a central process in a market economy, it refers to when new products or methods replace outdated ones, through a constant process of change. In the short term, it may result in job losses, business closures, and the collapse of entire industries. In the long term, it is understood to increase productivity and growth. *Disruptive innovations* create new markets, through new technologies and/or by using old technologies in new ways. They are innovations that make products and services more affordable and accessible. For example, personal computers created a mass market for computers. In the past, mainframe computers were used exclusively by research institutions and large firms.

(Aghion & Howitt, 1992, 1997; Christensen, 1997). However, there may also be concomitant increases in the demand for skills to design, maintain, and find innovative uses for other new technologies (Cowen, 2013).

4.2 NATIONAL OCCUPATIONAL PROJECTIONS

Projections of labour shortages and surpluses require forecasts of labour demand and labour supply of occupations (Freeman, 2006). There are several approaches to occupational projections, including workforce planning, econometric models, and labour market analyses (CCL, 2007b). These differ by types of models used, assumptions, data types and quality required, resources devoted to the task, goals, and types of information produced (CCL, 2007b; CSE, 2008). Macroeconomic and demographic models tend to form the basis for occupational projection systems (Hughes, 1993; Archambault, 1999; CCL, 2007b). In general, the quality of projections depends on the quality of the data and the assumptions made (CCL, 2007b). Because conditions are likely to change, the accuracy of forecasts decreases with the length of the forecasting period (CCL, 2007b; Hopkins, 2002, as cited in CSE, 2008) and as projections are disaggregated by skill type, occupation, and geographic region (Richardson & Tan, 2007; Meagher & Pang, 2011). Projection systems are also not generally adept at anticipating economic shocks or technological disruptions (see Timmermann, 2006; Wyatt, 2010) — a point that is particularly relevant to this discussion.

In Canada, a number of government organizations are involved with labour market forecasting at the federal, provincial, and territorial levels. Most rely on some form of COPS, a workforce planning tool run by EDSC. Provincial governments provide occupational employment forecasts, although the quality, type, and detail of information vary significantly (Sharpe, 2009). This section looks first at COPS projections for national labour markets, and then discusses the limitations of this type of occupational forecasting.

4.2.1 COPS Projections

COPS is designed to provide baseline indicators of future imbalances[17] between supply and demand for occupations over a 10-year outlook, *assuming current trends continue*. Thus, in the absence of any adjustments by employers, workers, or government, COPS provides a glimpse of what might occur. If adjustments take place in response to these trends (e.g., investments in employee training,

17 There is an important distinction between cyclical (short-term) imbalances and structural (long-term) imbalances. *Cyclical imbalances* are expected to be temporary and likely cleared out by market forces (adjustments by employers and workers), whereas *structural imbalances* may require sustained action by major players such as governments or large firms (see Centre for Spatial Economics, 2008).

wage increases to attract top workers, adjustments in immigration policy), it can be expected that the imbalances projected by COPS will not occur (Hughes, 1993). These are not intended to be actual predictions of the future, but rather indicators of trends to be used by students, employers, labour market entrants, workers, and governments as one of several pieces of labour market information (Hughes, 1993).

As an example, COPS projects that assuming trends continue, the labour market in Canada will be in balance as of 2022.[18] While some STEM-intensive occupations are currently experiencing imbalances, most are not — nor are they projected to be. However, imbalances are expected for two STEM occupational groups: (i) life science professionals (technical occupations in life sciences are in surplus); and (ii) civil, mechanical, electrical, and chemical engineers (see Table 4.1). To the latter point, a 2012 report for Engineers Canada suggests that demand will be skewed towards replacing retiring workers, rather than filling new jobs created as a result of expansion. Thus, while demand for experienced engineers may increase, it is expected to be weaker for new graduates (PEA, 2012) unless less experienced workers are trained and promoted, which may in turn create openings for new entrants (see also Table 6.1).

Table 4.1

COPS Projections for STEM-Intensive Occupations, 2022

NOC Code	Occupation	Recent Condition (2013)	Projected Condition (2022)
021	Managers in engineering, architecture, science and information systems	Balance	Balance
211	Physical science professionals	Balance	Balance
212	**Life science professionals**	**Shortage**	**Shortage**
213	**Civil, mechanical, electrical and chemical engineers**	**Shortage**	**Shortage**
214	Other engineers	Balance	Balance
216	Mathematicians, statisticians and actuaries	Balance	Balance
217	Computer and information systems professionals	Balance	Balance

continued on next page

18 The COPS website (http://www23.hrsdc.gc.ca/w.2lc.4m.2@-eng.jsp) presents projections by occupation. For each occupation, COPS presents data relating to the expected employment level, replacement demand, retirement level, job seekers, job openings, immigration, expansion demand, and school leavers per year over the projection period. The short term refers to two years into the projection period, the medium term refers to the mid-period in the projection period, and the long term refers to the expected end numbers per category.

NOC Code	Occupation	Recent Condition (2013)	Projected Condition (2022)
221	Technical occupations in physical sciences	Balance	Balance
223	Technical occupations in civil, mechanical and industrial engineering	Balance	Balance
224	Technical occupations in electronics and electrical engineering	Balance	Balance
225	Technical occupations in architecture, drafting, surveying and mapping	Balance	Balance
228	Technical occupations in computer and information systems	Balance	Balance

Data Source: ESDC (2014c)

Using NOC codes, this table of STEM-intensive occupations presents current and expected labour market conditions. The majority of STEM-intensive occupations are expected to continue to be in balance by 2022, and two are expected to be imbalanced.

4.2.2 Limitations of Occupational Projections

In general, COPS provides a tool for amalgamating diverse data on recent trends and current conditions in the labour market. This can be a useful input in decision-making, but it is not strong enough to guide skills policy on its own. The future is inherently uncertain, thus forecasts are imperfect (Meagher & Pang, 2011). However, it may not be appropriate to ask whether a forecast is better than none: if there is to be some sort of planning, then there must be some sort of forecast (Meagher & Pang, 2011). How much error between projections and actual outcomes is acceptable? A "reliable" forecast can only be considered to be one that is less unreliable than the best available alternative (Wyatt, 2010; Meagher & Pang, 2011). If the purpose of a forecast is to provide labour market information, the value of a forecast can be measured in terms of the costs of bad decisions made without them (CSE, 2008; Meagher & Pang, 2011). There is limited and mixed evidence in this regard, sometimes finding that occupational projections can reduce costs associated with uninformed decision-making (see Burns & Shanahan, 2000, cited in CSE, 2008) and, at other times, supporting what turned out to be a wrong decision (Hopkins, 2002, cited in CSE, 2008).

The Panel noted that a major problem in evaluating occupational projections is that the projection itself may lead to actions that prevent the projection from being realized (e.g., a projection of a nursing shortage may result in more individuals entering nursing school). Perhaps the biggest challenge to evaluating the reliability of a projection is actually deciding how to measure it, which requires an acceptable benchmark (Smith, 2002, cited in Hughes, 1993; CCL, 2007b; Wyatt, 2010). Because of the complexity of this task, systematic evaluations are rarely done (Haskel & Holt, 1999, cited in Richardson & Tan, 2007); (see also Wyatt, 2010).[19] Previous versions of COPS have been found to be roughly as accurate as French and U.S. projection systems (Hughes, 1993; Archambault, 1999).

Evaluations of occupational projections generally conclude that their main value is as indicators of overall trends and interdependencies; they are limited in their capacity to provide detailed forecasts (Richardson & Tan, 2007) and lack reliability to guide policy on skills development (Freeman, 2006). Most future projections are inherently unreliable because they are based on the assumption that historical relationships will continue in the future. However, technology and labour markets are dynamic influences that can strongly affect expected outcomes. As a result, long-term future demand is difficult to predict, especially demand for specialized skills. Given the inherent limitations of tools such as COPS, the Panel highlighted the importance of:

- access to quality labour market information, including detailed sub-provincial data on wages, vacancies, occupational employment, and unemployment (see Chapter 3 and Section 8.5); and
- equipping Canadians with skills that will enable them to adapt to inevitable technological changes and evolving labour market conditions.

4.3 SKILLS FOR THE FUTURE

Projections are limited in their ability to predict future occupational needs, and definitively determining the skills and knowledge required for these jobs is not possible. The creation of new occupations and the development of their related skills can outpace efforts to classify them (Stuckey & Munroe, 2013).

Although it is not possible to identify the specific skills and knowledge required for the jobs of the future, and to forecast the extent of the demand for them, research suggests that a flexible and adaptable workforce is a sensible response to growing uncertainty about the future of technology, the changing nature of work, and expected demands for skills (Cowen, 2011; Stuckey & Munroe, 2013; Brynjolfsson & McAfee, 2014). The Panel agreed that several assets are central to this proactive strategy: (i) fundamental skills for STEM; (ii) practical and advanced STEM skills; and (iii) complementary skills, which are increasingly recognized as important for applying STEM skills effectively in an organization or in a way that is relevant to the economy. While the Panel recognized that

19 A few national projection systems do periodic evaluations (e.g., Australia, Netherlands, United States), as recommended by some authors (typically those who work for agencies that are evaluating their own projections). There is no accepted benchmark to evaluate the accuracy of COPS projections (Smith, 2002, as cited in CCL, 2007).

an array of skills contribute to Canadian society and the economy, including those developed and used in the arts, social sciences, and humanities, STEM is the focus of the Panel's charge.

4.3.1 Fundamental Skills

Fundamental skills "provide the foundation for learning all other skills and enable people to evolve with their jobs and adapt to workplace change" (ABCLLC, 2015). Experts agree that developing strong fundamental skills in all individuals, including the fundamental skills that are required for STEM literacy, is essential to maintaining a productive society (Dion, 2014). As described in Section 1.2, the fundamental skills required for STEM include reasoning, mathematics, problem solving, and the ability to apply these skills in technology-rich environments. These skills can and should be learned from an early age, considering they are building blocks for STEM and non-STEM skills (this is the subject of Chapter 5). Beginning at this level of skills development, the Panel highlighted the importance of a long-term approach towards nurturing an educated population with the necessary skills to enable options in the face of an uncertain future. They agreed that the optimal mix of skills is likely specific to an individual because people possess different aptitudes and interests. A spectrum of basic skills is essential (Dion, 2014).

Evidence from cross-country growth regressions suggests that improved cognitive skills in terms of science, mathematics, and reading among the general population are associated with economic growth (Barro, 2001; Hanushek, 2013). Exploiting institutional differences in education across countries, Hanushek and Woessmann (2012) find evidence of a causal effect of increased cognitive skills on economic growth, using mathematics and science test scores as measures of cognitive skills. They are also able to distinguish between the effects of having a greater share of the population with general cognitive skills (scoring above a threshold on the tests) and a greater share of the population with high levels of cognitive skills (based on a higher threshold). They find that both have significant positive impacts on economic growth, and complementarities exist between having highly skilled workers to generate innovations and a large workforce with adequate skills to put the innovations to use.

In Canada, most of the population possesses some level of fundamental STEM skills, as demonstrated by international test scores (Chapter 5). However, as explained later in this report, much more can be done to improve these skills. While evidence from Chapter 3 suggests that STEM credentials can enable a range of career options, not everyone needs or wants a post-secondary degree, certificate, or diploma in a STEM field. Fundamental skills, however, are different — and thus merit unique policy responses. Given our inability to predict the future and the rate of technical change, it is important for all Canadians to be STEM literate.

4.3.2 Practical and Advanced STEM Skills

Cutting-edge work in highly technical fields requires individuals who have invested substantial time and effort in developing deep knowledge of relatively narrow fields. These investments are important for identifying problems that can be solved with existing technology, manufacturing and testing prototypes, basic research, and the development of new innovations. Building on fundamental skills, practical and advanced STEM skills enable these outcomes. As explained in Chapter 1, practical STEM skills include knowledge of established scientific principles and how to apply them to specific tasks or occupational roles. Advanced STEM skills include familiarity with scientific methods, conceptual design, specialized STEM discipline-specific training, and knowledge of disciplinary concepts. Both are generally acquired through the post-secondary education system, but also through professional training, experience, and recreational activities.

Specialists with a deep but narrow understanding of a single area are sometimes referred to as *I-shaped* individuals. Supports for these individuals are critical, especially considering what is known about the links between STEM skills, innovation, and productivity growth, and about the benefits of STEM credentials. However, given the uncertainty about future skill needs, the Panel cautioned that a focus on very narrowly specialized STEM skills development to meet short-term labour market requirements may have little relevance for meeting long-term skill requirements. It takes a significant investment to develop expertise in an area, but, as demonstrated in this chapter, it is often unclear which areas of expertise will prove fruitful in the future. The Panel noted that changes in demand for niche skills over time may result in an overabundance of skills that are obsolete or not valued. Further, making such a deep investment in one area has a high cost in terms of not developing other skill sets across society. Practical and advanced STEM skills are two examples of the many skill sets that are important to society and the labour market.

4.3.3 Complementary Skills

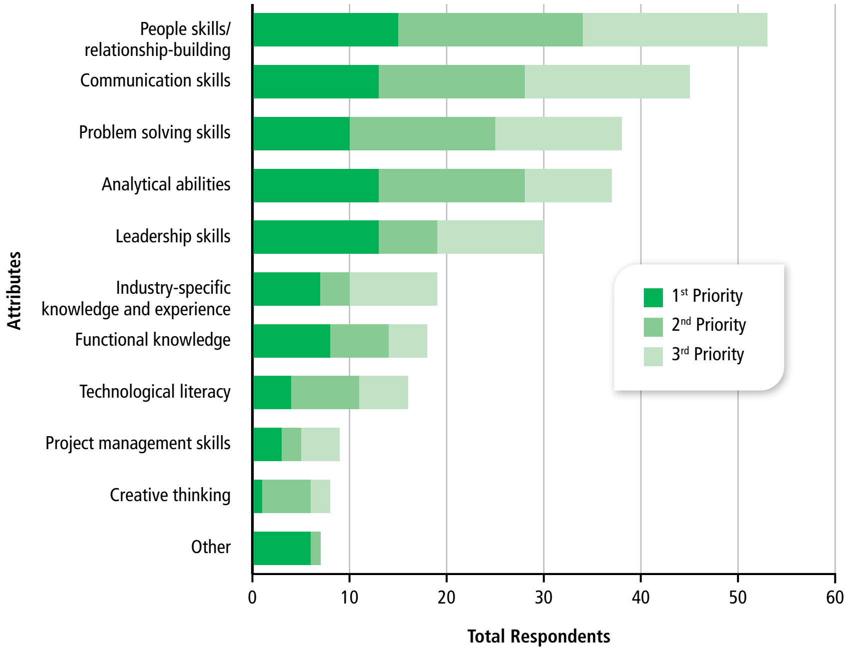
As presented in Chapter 2, innovation appears to be the primary channel through which STEM skills are understood to boost productivity, However, STEM skills are not the only driver of innovation. The Panel suggested that *complementary skill sets*, such as leadership ability, business skills, creativity, conscientiousness, and communication skills, may help enhance and maximize the impact of STEM skills in the innovation process (see also Chapter 6).

Further, evidence from business surveys suggests that in addition to technical expertise, employers value employees with the complementary skills required to work effectively in an organization. Thus, some advocate a push towards developing *T-shaped* individuals (Donofrio, 2009). T-shaped individuals have specialized knowledge in a narrow area (the "I") but also have a broader skill set and knowledge base upon which to draw (the bar shaped line, "–"). T-shaped individuals are understood to take a multidisciplinary approach and possess solid communication and teamwork skills that allow them to share insights with people from various backgrounds. The Panel refers to the combination of STEM skills and complementary skills as *STEM+*.

Until recently, there has been little research on the value of some of these complementary skills. Kautz *et al.* (2014) provides U.S. evidence that non-cognitive skills (defined as "personality traits, goals, character, and motivations that are valued in the labor market, in school, and elsewhere") matter for economic outcomes. Combining wage data with a list of job tasks and requirements from the Dictionary of Occupational Titles, Bacolod and Blum(2010) find that wage returns to "people skills"[20] increased considerably between 1968 and 1990, not because people skills themselves were becoming more valuable, but because their complementarity with cognitive and motor skills increased over the period. For a review of other economics research suggesting that complementary skills, personality traits, and attitudes lead to higher wages, see Balcar (2014).

As demonstrated by results of a 2013 Canadian Council of Chief Executives (CCCE) survey, employers value complementary skills (see Figure 4.1). People skills, communication skills, and problem-solving skills were ranked as the top attributes among entry-level job candidates (CCCE, 2014). Technical training remains important. Similar results were gained from a Canadian Association of Career Educators and Employers survey of 920 Canadian employers (Smith & Lam, 2013). From a list of 20 competencies, the most valuable to employers among new graduate hires were analytical skills, communication skills (verbal), problem-solving skills, strong work ethic, and teamwork skills. These five assets have recurred consistently for the past three iterations of the survey (in various orders).

20 In this study, *people skills* were defined as the "complexity at which workers perform jobs related to people, from highest to lowest: mentoring; negotiating; instructing; supervising; diverting; persuading; speaking-signaling; serving; taking instructions."



Reproduced with permission from CCCE (2014)

Figure 4.1

Top Attributes of Potential Entry-Level Hires According to Major Canadian Employers

Results are from a 2013 survey of more than 100 member firms of the CCCE. Hiring managers were asked the question: "In general, when evaluating potential entry-level hires (i.e., recent university/college/trade school graduates), which of the following attributes matter most to your company? (Rank top three)".

In terms of skill deficits, results from the Ontario Employer Skills Survey (n = 1538) reveal gaps in critical thinking and problem solving (over 70%), oral communication (46%), and literacy (42%). Numeracy was the least selected skills area, but 22% of employers still found deficits in this area (Stuckey & Munroe, 2013). The Canadian Education and Research Institute for Counselling's 2014 survey of 500 Canadian business leaders indicates that, for many employers, finding workers who possess adequate complementary skills is a challenge (CERIC, 2014). Of those interviewed, 66% reported difficulty in finding candidates with the complementary skills they were looking for: a positive attitude, good communication skills, and a strong work ethic. And 62% indicated their willingness to provide technical training to individuals with solid complementary skills if they were having difficulty finding workers with sufficient technical skills. Both these surveys, however, refer to skilled workers in Canada generally, rather than STEM-specific workers. For many STEM positions, it may not be reasonable for an employer to provide sufficient STEM training.

Evidence from STEM employers is found in international surveys. A 2013 Confederation of British Industry survey of employers in the United Kingdom reveals that 39% of firms have difficulties recruiting STEM-skilled staff (CBI, 2013). The three primary barriers to recruitment of these workers are lack of appropriate attitudes and aptitudes for working life, lack of general workplace experience, and the quality of STEM graduates. "A shortage of STEM graduates" is the fourth ranked barrier. A 2012 U.S. survey of 102 science and technology-based organizations finds that top skills sought include written and oral communication skills, technical skills associated with the job, making decisions and problem solving, adaptability and managing multiple priorities, and content-based knowledge. A majority of science and technology employers (68%) stated that recent graduates are prepared for job searches; however, out of eight industries, these employers reported that they experience the most difficulty in finding qualified recent graduates (CHE, 2012).

4.3.4 Moving Forward

Based on the Panel's understanding of these assets, Figure 4.2 illustrates several categories of STEM skills. At the base, STEM literacy is viewed as a prerequisite for a variety of education and career options. Students who have strong STEM literacy by the end of high school can look forward to a range of future education and career options. Their pathways may be in higher STEM education, STEM careers (including STEM-intensive careers defined in the Panel's methodology, as well as those careers that require some level of STEM skills), or non-STEM fields. What matters most is that young Canadians have a variety of choices and options available to them when they complete high school, so that they can make informed decisions. Raising Canadians' overall level of STEM literacy is understood to also increase the level of Canada's top performing STEM specialists. It is necessary to develop individuals with skills at all levels of the pyramid, as well as to provide support for those who do not complete high school to ensure that they too have ongoing opportunities to acquire fundamental skills (dotted lines). In addition to raising the level of STEM literacy in the general population through strategic investments in early education and the compulsory education system (pyramid base), the Panel agreed that complementary skills development can be enhanced to help activate practical and advanced STEM skills (middle and top of pyramid).

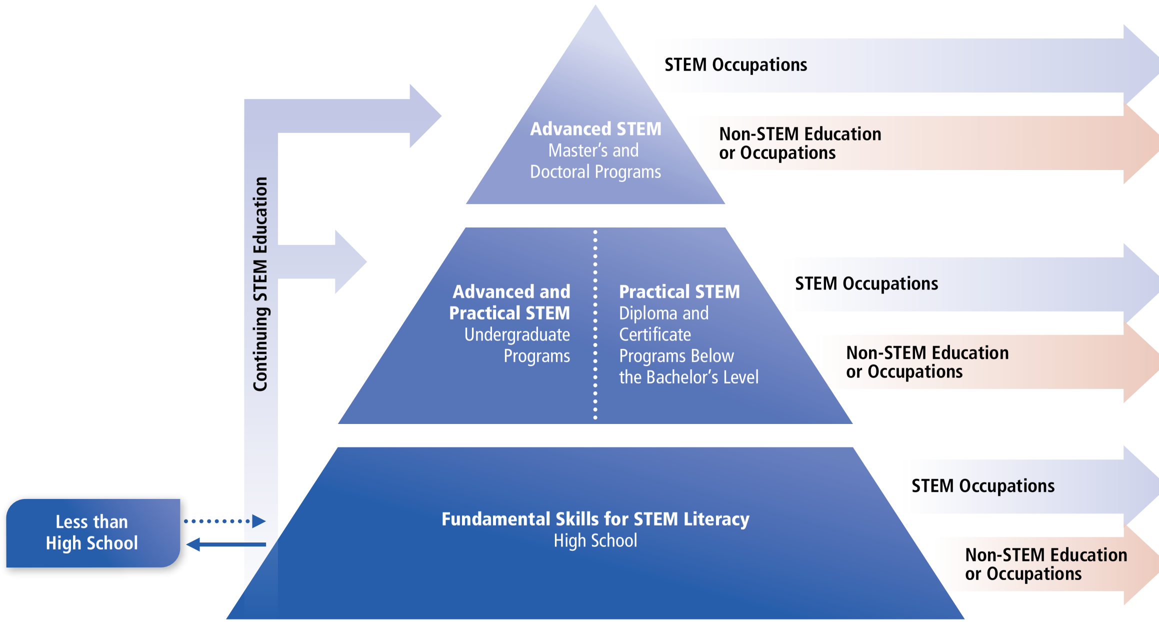


Figure 4.2

STEM Skills Enable a Range of Pathways

As described throughout Section 4.3, a range of STEM skills are valuable to individuals, society, and the economy. This pyramid aligns with the descriptions and classification scheme presented in Chapter 1. As the intent is to convey the relationships and distinctions among STEM skills, complementary skills are not depicted.

4.4 CONCLUSION

While precision regarding future skill requirements and labour market demands is not possible, empowering individuals with the skills to enable a range of economic possibilities appears to be a sound strategy given an uncertain future. The Panel concluded that long-term, sustained investments in fundamental skills for STEM literacy represent a sensible response to growing uncertainty about the future of technology, the changing nature of work, and expected demands for skills. The extent to which advanced STEM skills will be required is less clear than previously expected by some economists, especially considering trends suggesting the possibility of declining demand for routine cognitive skills in the United States since 2000. However, non-routine cognitive skills are still expected to command a premium over manual skills, and fundamental skills for STEM literacy remain important for all Canadians. This finding speaks to the importance of developing an educated society, with a strong base of fundamental skills for STEM that will open up a range of future options for students and workers — regardless of whether or not they intend to continue in STEM fields. At the same time, it remains critical to support basic R&D among those with the highest levels of STEM skills.

To facilitate these goals, the Panel agreed that a strong and sensible approach to developing a STEM-skilled society includes long-term commitment to STEM education, coupled with more comprehensive labour market information so that individuals can make informed choices. As previously highlighted, the Panel found that Canada appears to have a well-functioning labour market, with no evidence of a current imbalance of STEM skills nationally. Thus, specific interventions to increase the number of STEM-skilled workers do not appear warranted. The Panel cautioned that a focus on very narrowly specialized STEM skills development to meet short-term labour market requirements may have little relevance for meeting long-term skill requirements.

The next two chapters therefore examine how Canada can meet the need for STEM skills at two levels: (i) fundamental skills to promote overall STEM literacy from early childhood through high school, and (ii) practical and advanced STEM skills through post-secondary education and employer-sponsored training. Chapter 6 also considers how the post-secondary education system and employers can encourage the development of the complementary skills that are important for innovation, adaptability, and labour market success.

5

Meeting Future Needs for Fundamental Skills for STEM: Developing a STEM-Literate Society

5 Meeting Future Needs for Fundamental Skills for STEM: Developing a STEM-Literate Society

Key Findings

STEM literacy encompasses skill sets such as spatial orientation, conceptual abilities, hands-on manipulative skills, and basic technological design. These can be particularly well developed through STEM disciplines.

The fundamental skills that enable STEM literacy are the building blocks and prerequisites for a wide variety of future education and career options. These skills are important for all learners. Early and sustained high-quality interventions can help mitigate systemic disparities and equip the general population with the fundamental skills for STEM that are needed to enable a range of future options. From this population, some will pursue practical and advanced levels of STEM achievement.

Just as STEM literacy plays a special role in education, mathematics plays a special role within STEM. A strong early mathematical foundation supports student success in more advanced mathematics, as well as in science, reading, and non-routine problem solving.

Quality STEM teaching is critical to student success. This encompasses teacher preparation, teaching methodologies, and the use of engaging curricula. Policy-makers, educators, and parents all have a role to play in ensuring that children develop strong fundamental skills for STEM literacy.

Since the future demand for skills in general, and specialized STEM skills in particular, is difficult to predict, the Panel emphasized in Chapter 4 the importance of investing in the long-term goal of fostering an educated, adaptable population with strong fundamental skills. As will be explained at the outset of this chapter, the importance of these skills has been well established. Results from standardized tests demonstrate that Canadian youth perform relatively well in international assessments of ability in science and mathematics, but there remains significant room for improvement. This chapter then presents the factors in the Canadian compulsory education system that affect Canada's supply of STEM skills, from early childhood education through to high school. It closes with a review of interventions that can help equip students with fundamental skills for STEM, which are required for daily life as well as for a range of education and career options.

While Chapter 3 suggests that the market for STEM skills is reasonably self-regulating, pre-primary, primary, and secondary education in Canada is not a competitive marketplace governed by the normal forces of supply and demand. Thus, interventions in the form of strategic investments at different points in the education system are critical to promoting equity and excellence in education, as well as mitigating bottlenecks in Canada's supply of STEM-skilled individuals. Policy-makers, formal and informal educators, and parents all have a role to play in ensuring that all children develop the strong fundamental skills necessary for a STEM-literate society that reflects Canada's diversity.

5.1 FUNDAMENTAL SKILLS FOR ALL LEARNERS

The following sections demonstrate that the fundamental skills that enable STEM literacy are (i) important in themselves, (ii) critical to a range of other learning skills, and (iii) prerequisites for a wide variety of future education and career options. Such skills are important for all learners, not just those who (plan to) continue in STEM fields.

First, an introduction to *fundamental skills* is important (recall Section 1.2). A number of important and related skills, such as literacy and numeracy, are required to communicate and use numbers in ways that enable participation in society (Orpwood *et al.*, 2012). They are also crucial for higher-level learning. Fundamental skills are necessary to acquire knowledge in any field or discipline, and to be informed responsible members of an increasingly complex and sophisticated technological society. According to the Panel, these include capacities such as basic literacy, effective written and oral communication, numeracy,[21] inquiry, critical reading and thinking, problem solving, effective collaboration, and information literacy. Other competencies may also be included in this category, including socio-emotional skills, political literacy, and capacities for creativity and innovation (PE, 2013). The Panel noted that these skills, which are fundamental to all disciplines, can be learned and practiced in the pursuit of all school subjects (e.g., numeracy could be part of a history course in the same way that basic literacy could feature in a mathematics course) (see Dion, 2014).

21 According to the OECD, numeracy is the "ability to access, use, interpret, and communicate mathematical information and ideas, in order to engage in and manage the mathematical demands of a range of situations in adult life" (OECD, 2009).

5.1.1 Role of STEM Literacy in Education

This chapter focuses on the fundamental skills required for *STEM literacy*. This term refers to "the knowledge and understanding of scientific and mathematical concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity" (NRC, 2011).[22] STEM literacy is important for all students to expand their education and career prospects and develop into well-rounded citizens. STEM literacy can be developed through STEM education, which the Panel identified as a particularly strong environment in which to nurture the skills that are fundamental to STEM in a hands-on way. Such skills are foundational in the pursuit of STEM knowledge. According to the Panel, these include such capacities as grappling with mathematical structures, spatial reasoning, conceptual abilities, hands-on manipulative skills, design of algorithms, and basic technological design (see ITEEA, 2011; NAS, 2013) (recall Chapter 1). The design process used by engineers, technicians, computer scientists, and architects to develop solutions to problems is linked to STEM literacy, as are the skills required to calculate a mortgage, determine the best investments based on interest rates and returns over time, and develop, produce, use, and maintain technology (see Box 5.1). Fundamental skills for STEM are critical for the development of practical and advanced STEM skills, as well as enabling a range of future education and career options.

Strong foundations in STEM literacy also give students the flexibility to choose their own education pathways. Conversely, failure to attain fundamental skills for STEM can result in obstacles to desired career futures. For example, a Higher Education Quality Council of Ontario (HEQCO) report shows that about 20% of Red Seal trades apprentices surveyed in Ontario did not meet the minimum skill requirements for reading and document use in their trades, and 81% did not meet requirements for advanced mathematical skills, including geometry and trigonometry (Clark & Jurmain, 2014).

22 Empirical work linking scientific literacy to democratic engagement is limited, and no objective standards exist to determine a target level of knowledge in this regard. However, public understanding of science is recognized as a prerequisite for informed citizen engagement in science policy issues (CCA, 2014).

Box 5.1
Setting STEM Literacy Apart: Technology and Design

Technological literacy comprises "the ability to use, manage, assess, and understand technological products and systems." This requires particular capacities and mental skills, such as problem solving, troubleshooting, visual imaging, critical thinking, invention, innovation, and experimentation. Technological literacy begins when a student is given access to systems and configurations that are structurally rich and designed in interesting, instructive, or imaginative ways, whether by nature or through human ingenuity. Design, a facet of many disciplines and occupations, such as architecture, visual arts, urban planning, clothing manufacture, and esthetics, is increasingly regarded as the core problem-solving process of technological development. It calls for hands-on skills, such as measuring, drawing, using tools and multimedia, and/or working with computers. Design skills are valuable in and of themselves, but in the process of learning these skills, students can gain insight about transforming ideas into solutions, and increase their comfort with technology. The Panel agreed that while exposure to multiple approaches is useful, STEM education represents an excellent environment in which to build technology and design skills and these are in turn important for overall STEM literacy.

(ITEA, 2007)

Figure 5.1 highlights examples of critical success factors for STEM literacy that will ideally occur for all learners (blue), the focus of this chapter, and for those who will continue along the STEM pathway (green). Early academic skills, such as pre-literacy and early mathematics education, are critical to short- and long-term academic success. Children's early skills are connected to later success because they provide a foundation for more advanced skills (Claessens & Engel, 2013). As explained by Nobel-winning economist James Heckman, "early learning confers value on acquired skills, which leads to a self-reinforcing motivation to learn more, and…early mastery of a range of cognitive, social, and emotional competencies makes learning at later ages more efficient and therefore easier and more likely to continue" (Heckman, 2008).

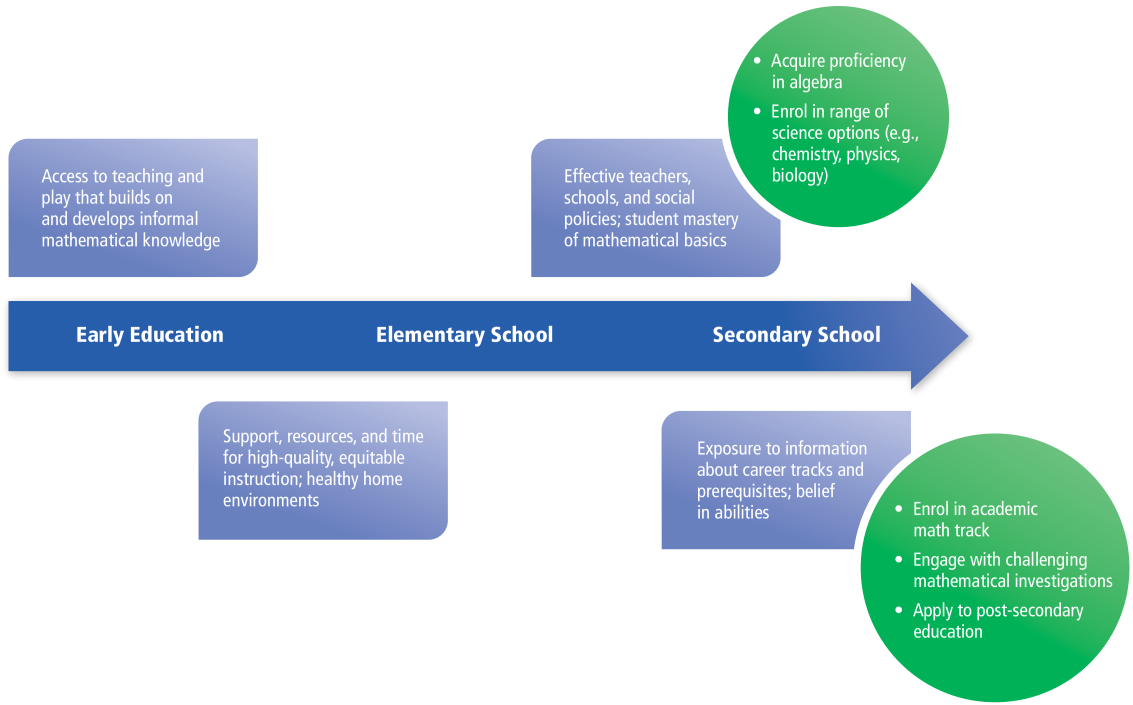


Figure 5.1

Pathways for STEM Literacy

The figure represents the general pathway of a student from preschool age to the end of high school. It shows the two different yet important goals of formal STEM education: STEM literacy for all learners and STEM literacy to develop future STEM professionals. Fundamental skills for STEM are essential to strengthen learning outcomes for all students, empower learners with the ability to develop more complex STEM skills, open doors to a range of options, and facilitate progression towards practical and advanced STEM skill acquisition. Spanning the compulsory and informal education spectrum and based on a synthesis of the literature, text in blue presents examples of actions and requirements for building STEM literacy for all; text in green provides examples of actions recommended for those who wish to continue in STEM education and/or careers. For example, the Panel agreed that mastery of mathematical basics is essential for all learners regardless of their career and life plans, but proficiency in advanced algebra and calculus is required for students who (may) wish to enrol and succeed in more advanced and specialized mathematics courses.

5.1.2 Role of Mathematics in STEM Literacy

Just as fundamental skills for STEM literacy play a role in education, mathematics plays a special role within STEM. A body of evidence, as cited in Bruce *et al.*'s 2012 meta-analysis of over 500 studies, suggests that providing children with solid grounding in mathematics learning supports student success not only in later mathematics, but also in the equally important domains of science, reading, and non-routine problem solving. In particular, the reasoning competencies of mathematics may build a basis for thinking and learning in a variety of subjects (Clements & Sarama, 2011). According to the U.S. National Academies of Science, learning mathematics early is not only important for later success in mathematics, but also for stronger academic results in literacy, science, and technology (Cross *et al.*, 2009).

Since children have the potential to develop mathematical skills at an early age, even at abstract and symbolic levels (Bruce *et al.*, 2012), early interventions are important to maximize the learning potential of children. Research from the past 30 years reveals that from birth to the age of five, young children develop an "everyday mathematics." These informal ideas, which are "surprisingly broad, complex, and sometimes sophisticated," can include concepts of more or less, shape, size, pattern, and location (Ginsburg *et al.*, 2008).

While causality can be difficult to establish in studies that examine early numeracy and mathematical skills as a predictor of later achievement, many of them demonstrate strong correlation. Research indicates that from the age of three, play with blocks and puzzles may lay foundations for spatial skills and STEM learning (Verdine *et al.*, 2013). Higher levels of preschoolers' block building have been shown to be predictive of Grade 7 mathematics scores, the number and level of mathematics classes taken in high school, average mathematics grades in secondary school, and greater reading ability in elementary school (as summarized by Lee *et al.*, 2012). Greater levels of numeracy in Kindergarten are also predictive of statistically significant and meaningful performance in mathematics achievement by the end of Grade 3 (Jordan *et al.*, 2009).

Early mathematical skills research reveals continuity in mathematical achievement over time (Claessens & Engel, 2013). For example, Duncan *et al.* (2007) examine data from six large-scale longitudinal studies in the United States, United Kingdom, and Canada, which include measures of academic success for five and six year-olds. Across all six studies, results show early mathematics concepts, such as knowledge of numbers and ordinality, to be the most powerful predictors of later learning, followed by early language, reading, and attention skills. Importantly, controlling for cognitive ability, they find that early mathematics is a stronger predictor of later reading achievement than early reading is of later mathematics achievement (Duncan *et al.*, 2007). The links are similar for both men and women regardless of socio-economic background, although it is possible that the effects are not causal. This brings meaning to the statement that "mathematics education is (in part) education in language and literacy" (Ginsburg *et al.*, 2008); language and mathematical skills are required to express mathematical reasoning, hypotheses, interpretation, recalling facts, and revising and reflecting (MOE & DSBs, 2005). Clear and careful thought emerges from precise language.

Similarly, Claessens & Engel (2013) find that early mathematical skills are predictive of reading, mathematics, and science achievement, as well as grade retention from Kindergarten through Grade 8. Their research is based on U.S. data from the Early Childhood Longitudinal Study of 7,655 children, and controlled for a wide number of variables (e.g., cognitive ability, child health, home environment, parental characteristics, neighbourhood). In Kindergarten, mathematical skills in pattern recognition, measurement, and advanced numbers were the most predictive of overall outcomes in Grade 8. The value of these skills[23] for later achievement was maintained or increased over time, suggesting that a greater focus on these skills in Kindergarten classrooms may help children develop skills from which they will benefit in later years (Claessens & Engel, 2013). Again, similar patterns of results were found across various subgroups of students (by gender, ethnicity, socio-economic status, etc.), suggesting that mathematical skills are important predictors of academic outcomes for all students (Claessens & Engel, 2013).

The 2011 data from the International Association for the Evaluation of Educational Achievement's Trends in International Mathematics and Science Study show strong positive associations between student achievement in Grade 4 and early learning experiences (e.g., attended early education programs, were able to perform basic addition and subtraction before beginning Grade 1, and had parents who engaged in early numeracy activities with them) (IEA, 2011). Home resources for learning and high expectations for education were linked with higher mathematics and science achievement at Grades 4 and 8. Similarly, linked Canadian Youth in Transition Survey/Programme for International Student Assessment (PISA) data show that 15-year-old students with strong mathematical and reading skills attain higher levels of education than those with low scores (Hansen, 2010).

23 Including the ability to read all 1-digit numerals, count beyond 10, recognize a sequence of patterns, and use nonstandard units of length to compare objects.

This sample evidence makes a clear link between the role of early mathematical skills and the later acquisition of knowledge in a variety of fields. Beyond providing a foundation for later STEM skill building, these skills appear to be positively linked to reading, for example. Thus, in addition to supporting children's learning in general, a solid grounding in fundamental mathematics is essential for learners to continue to acquire practical and advanced STEM knowledge and skills. The latter represents an important step towards developing a strong pool of STEM-skilled members of society.

5.2 INTERNATIONAL TESTS OF SCIENCE AND MATHEMATICS KNOWLEDGE: CANADIAN RESULTS

The value of fundamental skills for STEM literacy has been well established. However, no empirical evidence is available to definitively establish concrete targets with respect to an ideal level of STEM skills in the general public. Goals in this area are subject to judgment and, in part, are a reflection of the value that society places on these skills, both in terms of their beneficial effects and their non-instrumental importance (i.e., the extent to which society privileges knowledge, exploration, curiosity, innovation). Based on the measures that do exist, there is no evidence that Canada's general population faces an acute deficit of fundamental skills for STEM. Canadians are highly educated by international standards (Chapters 3 and 6) and, as will be demonstrated shortly, Canadian students excel in international assessments of youth ability in science and mathematics (Brochu *et al.*, 2013). Similarly, compared with other countries, Canadians possess a relatively high level of general science literacy based on public survey questions (CCA, 2014). International adult test scores suggest that Canadian adults perform well in numeracy, literacy, and problem solving in technology-rich environments. While these are positive findings, a closer look at the data suggests room for improvement in a number of areas. Interventions in these areas are important if Canada is to develop a STEM-literate population with the fundamental skills that are required to (i) open a range of career and education pathways, (ii) build resilience to future labour market uncertainties, and (iii) support technological innovation.

5.2.1 Youth Scores

PISA is an international OECD survey that measures trends in learning outcomes at age 15. It has been administered every three years since 2000, providing an opportunity to monitor performance changes over time. In 2012, it was administered in 65 countries (OECD, 2014c). Canadian students perform well in PISA, with relatively high scores on all domains (reading, science, mathematics, and problem solving) (Brochu *et al.*, 2013). Countries and economies scoring higher than Canada are generally in the Asia-Pacific region, of which nine outperform Canada at a statistically significant level in mathematics, and seven outperform Canada in science (Brochu *et al.*, 2013). Among G8 countries, Canada ranks second only to Japan on mean science and mathematics scores (see Table 5.1). For innovation and economic growth, research has highlighted the importance of top performers (Salzman & Lowell, 2008), whereas high average scores are generally indicative of equity in the general population.

While these are strong outcomes, 2012 scores show statistically significant declines in mathematics and science scores, from both a relative and absolute perspective. Canada's science score declined by nine points from a 2006 peak, and its mathematics score declined by 14 points since a 2003 peak (Table 5.2). The Panel agreed that these changes reflect the addition of new countries and regions to the data set, as well as absolute declines in Canada's mean scores.

Table 5.1

Countries or Economies Performing Significantly Better than or as well as Canada: Mathematics and Science, PISA, 2012

	Performing Better than Canada	Performing as well as Canada
Mathematics	Shanghai-China, Singapore, Hong Kong-China, Chinese Taipei, Korea, Macao-China, Japan, Liechtenstein, Switzerland	Netherlands, Estonia, Finland, Poland, Belgium, Germany, Vietnam
Science	Shanghai-China, Hong Kong-China, Singapore, Japan, Finland, Estonia, Korea	Vietnam, Poland, Liechtenstein, Germany, Chinese Taipei, Netherlands, Ireland, Australia

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

The table lists countries performing statistically significantly better than or as well as Canada on the overall mathematics and science scales.

Table 5.2

PISA Science and Mathematics Scores for Canada, 2003–2012

	PISA 2003	Rank (out of 41 countries and economies)	PISA 2006	Rank (out of 57 countries and economies)	PISA 2009	Rank (out of 65 countries and economies)	PISA 2012	Rank (out of 65 countries and economies)
Canada's Mean Score on Mathematics	532 (500)	3rd	527 (498)	5th	527 (497)	8th	518 (494)	10th
Canada's Mean Score on Science	519 (499)	5th	534 (500)	3rd	529 (501)	7th	525 (501)	8th

Data Source: Bussière *et al.* (2004, 2007); Knighton *et al.* (2010); Brochu *et al.* (2013)

Since 2003, Canada has continued to perform above the OECD average in mathematics and science. OECD averages are listed in brackets. Ranks are based on the number of countries or economies that performed statistically significantly better than Canada in each domain.

In addition to mean scores, the Panel was interested in the gap between high and low achievers. 2012 results show wide differences in mathematics and science performance in some countries, with more than 300 points (equivalent to about seven years of education) separating the highest and lowest achieving mathematics students (Brochu *et al.*, 2013; OECD, 2014d). The gap between high and low achievers in mathematics and science is smaller in Canada than in OECD countries on average. However, gaps are particularly noticeable at the provincial level: overall, the largest equity gaps in mathematics were observed in Alberta and Quebec, and the smallest in Nova Scotia (Brochu *et al.*, 2013). National scores obscure socio-demographic differences in general in Canada: students who are first-generation immigrants have lower than average literacy scores (Picot & Hou, 2012); statistically significant gender differences exist in mathematics achievement (Brochu *et al.*, 2013); and data from the three territories and First Nations schools are lacking (Brochu *et al.*, 2013). Closing the gap is partly about equity, but raising the level of the lowest achievers can also improve overall averages — translating into increased STEM capacity and diversity. The Panel noted that high performance should not be sacrificed to achieve equity, and vice versa (see Sahlberg, 2011). The success of high-performing students in Canada suggests that this is not currently a major concern.

In terms of top performers in Canada, 16.4% of mathematics students achieved the Level Five or Six benchmarks (out of six levels) in 2012. Canada ranks above the OECD average (12.6%) as well as above countries such as Sweden, the United States, and the United Kingdom. Canada is comparable to Finland and Poland, but remains significantly behind leaders such as Shanghai-China, (55.4%), Singapore (40.0%), and Korea (30.9%) (OECD, 2014d). Since 2003, Canada's share of top mathematical performers has decreased by 3.9% (compared with a 1.5% fall in the OECD average); since 2006, the proportion of top scientific performers has decreased by 3.1% (0.5% fall in the OECD average) (OECD, 2014d). The Panel suggests that providing students with opportunities for creative investigation with the support of strong teachers and engaging mathematics and science curricula may encourage more students to connect with these subjects, and potentially lead to more high achievers. This, however, is difficult to demonstrate empirically.

5.2.2 Adult Scores

While PISA results indicate that youth in Canada perform strongly on tests of scientific and mathematical literacy, outcomes from the OECD's Programme for the International Assessment of Adult Competencies (PIAAC) suggest that among older populations, Canada does not perform as strongly in general. Results from more than 27,000 Canadians aged 16 to 65 in 2012 indicate that across all three domains of literacy, numeracy, and problem solving in technology-rich environments, Canada has a larger proportion of adults at the lowest proficiency levels compared with the OECD average (StatCan, 2013e). Compared with the OECD average, there are also more outliers at both ends of the skill spectrum (CMEC, 2013).

In numeracy, Canada ranks below the OECD average (269) with a score of 265. Canadian adults scored similarly to those in Korea (263) and the United Kingdom (262), but lower than Japan (288), Finland (282), and Sweden (279) (StatCan, 2013e). All provinces and territories scored at or below the OECD average (StatCan, 2013e). The proportion of Canadians at the two highest levels of numeracy is equal to the OECD average (13%), while the share of those scoring in the two lowest levels of numeracy (23%) is greater than the OECD average (19%) (StatCan, 2013e). The latter group of Canadians are able to perform only simple mathematical tasks, such as counting or ordering. In problem solving in technology-rich environments,[24] Canadians (37%) outperform the OECD average (34%) (StatCan, 2013e). Compared with the OECD average, higher proportions of Canadians scored at the highest and lowest levels of proficiency in this domain (StatCan, 2013e), which may be indicative of a digital divide.

In addition to provincial variations, scores across the general population are driven by a number of socio-demographic variables. Such data may hint at why Canadian adults do not perform as well as Canadian youth on international tests. For example, compared with the general population at the lowest levels of proficiency in numeracy (23%), there is a higher proportion of adults with less than a high school education (51%), adults not in the labour force (35%), immigrants (33%), adults whose first language is not the same as the test-language (33%), older adults (28%), and Aboriginal peoples (25%) (CMEC, 2013). An analysis by Hango (2014) finds that field of study also affects scores. STEM graduates form a statistically significantly smaller proportion of those at the lowest two levels of proficiency for both literacy (9%) and numeracy (12%) skills, compared with graduates of teacher training and education science (22% at the lowest levels of literacy and 29% at the lowest levels of numeracy) and humanities, languages, and arts (18% and 29%) (Hango, 2014).

24 "Using digital technology, communication tools and networks to acquire and evaluate information, communicate with others and perform practical tasks. The first PIAAC problem-solving survey focuses on the abilities to solve problems for personal, work and civic purposes by setting up appropriate goals and plans, and accessing and making use of information through computers and computer networks" (OECD, 2012b).

5.2.3 Interpreting the Scores

PISA and PIAAC data produce internationally comparable findings that can inform interventions and policy-making (Gal & Tout, 2014; OECD, 2014e). The methodologies of the PISA and PIAAC surveys are different, precluding direct comparisons between the two. Nevertheless, the Panel suggested that more equity in education and higher-quality teaching at younger ages may be linked to more equity and higher mean scores in future skills outcomes.

The Panel cautioned that standardized tests represent only one method of measuring ability, and there is little evidence indicating that these test scores are relevant to innovation, economic competitiveness, and science and engineering performance (Salzman, 2013). International tests are limited in their ability to assess the multiple types of student knowledge and assets that are required for STEM careers, such as complementary skills. They represent only one measure of success, representing specific skills and competencies. The average scores of the students tested do not indicate the eventual performance of the population that ends up in a STEM career (Salzman, 2013). Further, the highest achieving mathematics and science students may not actually start or stay in STEM occupations. They may choose to "divert" into other educational and career tracks (see Carnevale *et al.*, 2011).

While the Panel noted the limits of such tests, it agreed on the importance of benchmark data. The value of fundamental skills and STEM literacy has been well established as important knowledge sets that enable a range of future career and education pathways. It is important to track where Canada is doing well, and where improvements may be warranted.

5.3 THE IMPORTANCE OF EARLY INTERVENTIONS

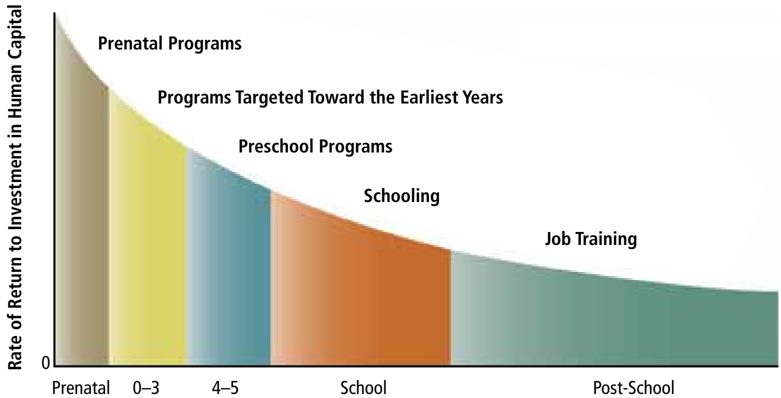
Canadian students perform comparatively well on international mathematics and science tests, and Canada's public education system is widely known for its quality. However, there are many opportunities to improve students' overall levels of STEM literacy, as well as to develop a pool of top performers. Skills development is an ongoing process, and the early years are critical for developing the foundations upon which later investments will build (Kautz *et al.*, 2014).

Children's participation in quality early education programs has been identified as a "major source" of human capital benefits (Pascal, 2009). Compared with interventions that begin in adolescence, the evidence base is larger for the long-term efficacy of efforts that target young children. Available evidence suggests that although adolescent remediation is possible, even the most successful programs with this goal remain less effective than the most successful early childhood and elementary school programs (Kautz *et al.*, 2014). Based on their analysis, the Panel agreed that early educational interventions represent one of the best ways to ensure that all Canadians acquire the basic STEM knowledge and skills required for daily life, as well as to set the foundations for education and skills training required for the jobs of today and tomorrow (see NRC, 2011). While different learners will eventually express different attitudes and aptitudes for STEM, expert consensus clearly shows that young children can learn ideas and skills necessary to support more complex mathematical engagement and understanding (Ginsburg *et al.*, 2008; Cross *et al.*, 2009; Bruce *et al.*, 2012). High-quality early instruction is required to capitalize on these abilities (Bruce *et al.*, 2012).

PISA data from 2012 show that students who attended early childhood education for more than one year scored 53 points higher on mathematics at age 15 (equivalent to more than a year of formal education) than those who did not attend (OECD, 2014f). A limited number of Canadian children are enrolled in early childhood education programs: in 2010, only 1% of Canadian three year-olds (compared with an OECD average of 67% in 2011) and 48% of four year-olds (OECD average of 84% in 2011) were enrolled in early childhood education at the pre-primary level (OECD, 2013b). Compared to Canada, all other OECD countries except for Turkey, Chile, and Ireland had a greater percentage of students who were educated for more than one year at the pre-primary level (OECD, 2013d).

Because informal mathematics knowledge forms the basis for understanding more complex mathematics taught in school, gaps in informal knowledge should be identified and addressed in preschool and early school years (Baroody *et al.*, 2006). According to the Expert Panel on Student Success in Ontario, “All students can learn mathematics — with enough support, resources and time — and we must ensure that they do” (EPSSO, 2004).

Research shows that investments in the early years, especially for at-risk children, yield the greatest returns and are economically efficient (Heckman, 2008) (see Figure 5.2). The advantages gained from effective early interventions are maximized when followed by other quality learning experiences (Heckman, 2008). In the absence of high-quality early mathematics instruction, students who start behind continue to be at a disadvantage due to a persistent gap that can widen during the course of their education (Cross *et al.*, 2009; Bruce *et al.*, 2012). Already at the preschool age, “striking” differences in children’s number sense emerge (Cross *et al.*, 2009). This is meaningful considering number sense in Kindergarten is predictive of success in mathematics in elementary school and beyond (Cross *et al.*, 2009).



Reproduced with permission from Heckman (2008, 2014)

Figure 5.2

Returns to a Unit Dollar Invested in Education

Nobel laureate in economics James Heckman shows that stronger yields of investment are revealed during the early years, supporting the curve depicted here. He argues that the most reliable data are derived from experiments that enrich the early environments of children in low-income households. When suboptimal investments are made in the ages of zero to three, returns to later investment are compromised.

Intersecting factors such as gender, Aboriginal identity, socio-economic background, culture, language, and ability can affect equitable learning opportunities (CCA, 2012b; Lee *et al.*, 2012). For example, despite strong public education efforts, major reports show that children from low socio-economic environments generally lag behind those from more privileged backgrounds (Cross *et al.*, 2009; Bruce *et al.*, 2012). In Canada, the disparity is particularly acute for Aboriginal children, who, due to a range of social determinants, experience gaps in academic achievement that emerge in elementary school and intensify at higher grades (Richards & Scott, 2009; Richards, 2014). International PISA results show that children of professionals and managers consistently score higher on the mathematics component than children of less occupationally skilled parents (OECD, 2014g).

On a positive note, while low socio-economic status children demonstrate weaker mathematical performance than their peers, they exhibit several competencies on which early childhood education can build, such as basic mathematical skills or concepts, non-verbal addition and subtraction problems, and the ability to engage in everyday mathematics during free play (Ginsburg *et al.*, 2008). Providing children with quality early instruction can address long-term systemic inequities in outcomes, as well as create a foundation for continued mathematics learning

(Cross *et al.*, 2009; Bruce *et al.*, 2012). While Canadian research shows that effective early learning programs are particularly important for some children, they can benefit all (Pascal, 2009). Pascal makes the case for quality universal programs with embedded poverty reduction initiatives; policies targeted only towards socio-economically disadvantaged children and families may miss a significant number of vulnerable children.[25]

The U.S. National Mathematics Advisory Panel concluded that support-focused interventions that address social, motivational, and affective factors are a promising means for reducing mathematics achievement gaps for under-represented groups. This is partly based on research that documents the association between social and intellectual support from peers and teachers with students' stronger mathematics performance — especially for students from minority groups. The U.S. Advisory Panel also recommended a focal shift away from *mathematical ability* towards *effort*. When children believe that increased effort is linked with increased performance, they demonstrate greater persistence in mathematics learning (NMAP, 2008).

Strong positive relationships have been found between students' attitudes towards mathematics and science (e.g., self-confidence, enjoyment of the subject, motivation) and academic achievement in these subjects (IEA, 2011; Sanci, 2014). Meta-analyses indicate that positive attitudes towards mathematics are related to lower levels of math anxiety, and that math anxiety is generally related to poor performance and avoidance (Hembree, 1990). Considering the positive relationships among students' perceptions of teacher support, attitudes towards mathematics, and achievement outcomes (see Midgley *et al.*, 1989), parents and formal and informal educators alike have key roles to play in promoting favourable attitudes towards mathematics, eliciting positive learning experiences, and ultimately helping students succeed in mathematics (Sanci, 2014).

5.4 TEACHER PREPARATION AND SUPPORT

A tension exists in early mathematics education. While children's mathematical potential is vast, many early childhood educators are unaware of the research findings related to mathematics and young children, and lack strong backgrounds in mathematics (Perry & Dockett, 2008; Cross *et al.*, 2009; Bruce *et al.*, 2012). The latter issue is particularly important considering the results of studies indicating that teachers' mathematical knowledge is positively related to student success (NMAP, 2008). Although the relationship is difficult to measure, notable

25 Not all vulnerabilities are income-sensitive. Some may be based in health, employment demands, living conditions, minority ethnocultural or linguistic status, and limited time or resources (Pascal, 2009).

differences in student mathematics achievement are linked to differences among teachers (NMAP *et al.*, 2008). For example, using data from 79 U.S. elementary schools, Nye *et al.* (2004) find that teacher differences explain 12 to 14% of the variation in students' mathematical achievement gains in each of Grades 1, 2, and 3. The variance of teacher effects in mathematics is about twice the size of their variance in reading.

While research that explains student achievement is mixed, Rivkin *et al.* (2005) find the influence of teacher effectiveness on school quality to be so great that the effects of reducing a class size by 10 are less than the benefit of one standard deviation increase in teacher quality (Rivkin *et al.*, 2005). Cross *et al.* (2009) report that teacher education and training often emphasize children's socio-emotional development and literacy at the expense of mathematics. While all of these skills are important, the authors assert that "academic activities such as mathematics can be a context in which social-emotional development and the foundations of language and literacy flourish" (Cross *et al.*, 2009).

As opposed to a criticism of teachers, Bruce *et al.* (2012) suggest that these concerns indicate a need to improve teacher education by supporting teachers in learning mathematics and mathematics pedagogy, providing more rigorous content during student-teacher practicums, as well as offering ongoing professional development:

> To ensure that all children develop the mathematics foundation they need for academic and overall success, teachers, curriculum developers, district personnel, researchers and policy makers need to transform their approaches to mathematics education by supporting, developing and implementing research-based practices.
>
> (Bruce *et al.*, 2012)

Despite the absence of strong empirical evidence that identifies the exact type of mathematical knowledge and skill required for quality teaching,[26] experts agree that teachers are vital to students' mathematics learning (NMAP *et al.*, 2008) (see Box 5.2). The Panel added that this finding highlights the need for more research to determine these assets.

26 Most studies to date have relied on proxies for knowledge, such as teacher certification or courses taken (NMAP *et al.*, 2008).

Box 5.2
Effective Mathematics Teaching

A U.S. National Academy of Sciences report identifies five essential areas of knowledge that early childhood educators require to be effective. They include knowledge of the mathematical content they will be teaching, children's learning and development, effective mathematics pedagogy, effective means for assessing children's development and learning, and available resources and tools for teaching early childhood mathematics.

In addition, it is important for teachers to have a positive attitude towards mathematics, believe that young children are capable mathematics learners, and believe that mathematics is appropriate in the early childhood classroom.

(Cross *et al.*, 2009)

Confident and innovative teachers are important, but teachers alone cannot surmount the challenges of educating diverse learners with different needs. Effective schools and social policies are also essential (Sahlberg, 2013). Box 5.3 looks at examples from Finland.

Box 5.3
Lessons from Finland

Hundreds of educators and policy-makers annually travel to Helsinki to learn about the Finnish model for student success. Finnish education expert Pasi Sahlberg explains that while contextual influences may render some reforms more feasible in Finland than in other jurisdictions, "these factors alone don't explain all the progress and achievements in education…and they should not stop us from learning from one another as we strive to improve education for all students" (Sahlberg, 2011).

Characterized by a successful, slow and steady approach to education reform that began in the 1970s, Finland instituted a comprehensive school system with the intent to serve all students equally well (OECD, 2010; Sahlberg, 2011). The principles of equal opportunities for good public education for all and the professionalism of and trust in teachers have guided Finnish education policy to where it is today (Sahlberg, 2011).

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Finland's national core curriculum is a framework within which teachers are free to select their own classroom materials and assessment methods (OECD, 2010). Thus students learn how to take charge of their own learning through witnessing their teachers' creative efforts to design their own curricula. How can the teachers manage to do this? Finnish teachers spend less time in the classroom than the OECD average, and engage in substantial amounts of professional learning and curricular collaboration with other teachers (Sahlberg, 2011). All teachers require a master's degree from Finland's academically rigorous teacher education program as well as compulsory in-service teacher training, both of which contribute to a high degree of professional respect. Of note is the fact that students who wish to teach primary school are chosen from the top 20% of high school graduates (Sahlberg, 2011).

While Finland is a strong performer in general, a closer look at mathematics and science learning in Finnish schools is useful in the context of the Panel's charge:

Mathematics: Mathematics teaching is a core component of the teacher education curriculum; as a consequence, primary school teachers understand how to teach and assess mathematics. Faculties of mathematics and education collaborate closely in the design of these curricula and, as a consequence, problem solving and "real-world" issues are emphasized at all levels of the school system.

Science: Primary school teacher education has been redesigned to help new teachers encourage students to engage with hands-on science learning. In general, an increasing number of new primary school teachers have studied science education during their teaching programs, and are able to understand and teach experiment and problem-oriented curricula.

Effective curricula are another component of effective teaching and effective schools. Just as there are many definitions of STEM, there are many definitions of STEM education. A commonly cited example is as follows:

> An interdisciplinary approach to learning where rigorous academic concepts are coupled with real-world lessons as students apply science, technology, engineering, and mathematics in contexts that make connections between school, community, work, and the global enterprise enabling the development of STEM literacy and with it the ability to compete in the new economy.
>
> (Tsupros *et al.*, 2009).

While education in individual STEM disciplines has a long and relatively successful history, STEM education as a meta-discipline is relatively new in Canada (Krug, 2012). There are, however, a number of innovative formal and informal STEM initiatives in teaching and learning inside and outside of the country, some of which focus on improving STEM literacy through inquiry-based and integrated learning strategies (Table 5.3).

Table 5.3

Examples of Promising STEM Education Initiatives

Program	Description
I³ Project: Invention-Innovation, and Inquiry: Units for Technological Literacy **(International Technology and Engineering Educators Association, ITEEA)**	The I³ Project provides professional support for elementary school teachers interested in technological literacy. Based on the premise that invention and innovation are the hallmarks of technological thinking and action, and rooted in the *Standards for Technological Literacy*, units include teaching approaches and activities, including brainstorming, visualizing, testing, refining, and assessing technological designs. http://www.iteea.org/i3/index.htm
Engineering byDesign (ITEEA)	This standards-based model helps to build technological literacy among all students. Classroom course units, tailored for elementary, middle, and high school students, focus on inquiry, communication, transportation, invention and innovation, technology and society, and design. The program aims to increase students' knowledge in technology, science, math, and English. Beyond helping students become informed citizens, Engineering byDesign provides students with the skills they need should they wish to engage in additional technological study beyond high school. http://www.iteea.org/EbD/ebd.htm
Project 2061 (American Association for the Advancement of Science)	Examples of R&D initiatives: • Green Schools as a Context for Science Learning uses school buildings to help students understand energy use; • WeatherSchool@AAAS.org is a partnership with NASA that enables students to analyze patterns in data collected by weather stations and satellites; • New Tools for Teaching Evolution assists high school students as they learn about evolution through mathematical reasoning and data analysis. http://www.aaas.org/program/project2061/research
Facing the Future: Global Sustainability Curriculum and Teacher PD	Using a sustainability framework, Facing the Future aims to strengthen students' STEM capacity at the middle school level to better prepare them to study STEM subjects. The framework is based on social, economic, and environmental issues to encourage students to develop systems thinking, critical thinking, and problem-solving skills. http://www.facingthefuture.org

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Program	Description
Centre for Science, Mathematics & Technology Education, (Ontario Institute for Studies in Education)	The Centre provides opportunities for collaborative research with Canadian and international groups, curriculum development and enriched teacher education courses specific to STEM, and a research seminar series that brings practitioners together. The Centre has also established Canada's first academic journal in this field. http://www.oise.utoronto.ca/smt/Resources/SMT%20Brochure%20 2010%20(small)a.pdf
Actua	Actua is a Canadian national charity that supports a network of university-based members who deliver hands-on STEM programs to 225,000 youth annually in 500 communities across Canada. Actua supports STEM in schools through curriculum-enhancing workshops and further enhances STEM literacy through informal learning opportunities including after-school and weekend clubs and summer camps. Actua delivers customized programs for under-represented youth including girls, Aboriginal students, and at-risk youth. www.actua.ca
Career Moves (Perimeter Institute for Theoretical Physics)	Career Moves: Skills for the Journey is a Canadian educational resource designed to help students recognize the essential skills needed for career success. Delivered in schools by trained teachers, it highlights the role of STEM in the development of key traits — including curiosity, collaboration, critical thinking, and an entrepreneurial spirit — that will fuel their future success. Career Moves is part of the Perimeter Institute's BrainSTEM initiative to advance STEM literacy and is the result of extensive collaboration with experienced guidance counsellors, and classroom teachers. https://perimeterinstitute.ca/store/perimeter-brainstem/career-moves-skills-journey
CurioCity (Let's Talk Science)	CurioCity is an interactive, web-based hub where teenagers (Grades 8 to 12) can connect with post-secondary students and science professionals to explore real-life science, engineering, and technology issues. Students can ask questions to graduate students and science professionals, get help with homework, and learn about science-related careers. There are also resources for teachers. http://www.explorecuriocity.org/
PROTIC – Programme de formation intégrant les nouvelles approches pédagogiques et les technologies de l'information et des communications (Collège des Compagnons)	Since 1997, this Quebec-based program has promoted the use of information and communication technologies (ICTs) as central to skills development. Thus, ICTs are integrated into all high school courses, rather than used in a separate and/or abstract manner. Teachers aim to foster team-based problem solving, technological literacy, and entrepreneurial skills among the 450 students who are currently enrolled. http://www.csdecou.qc.ca/collegedescompagnons/protic/
PREST – Pôle régional pour l'enseignement de la science et de la technologie	PREST is a non-profit pedagogical development centre for the teaching of science and technology. With a focus on scientific experimentation, observation, inquiry, and debate, PREST provides resources for preschool through to secondary school teachers and administrators across 10 school boards in Quebec. https://prest.csbe.qc.ca//index.php?lang=en

5.5 CONCLUSION

International standardized test scores indicate that compared with the OECD average, a higher proportion of Canadian adults score at the lowest proficiency levels across all domains of numeracy, problem solving, and literacy. There are also indications of an unequal distribution of these skills, with a relatively high proportion of Canadians at each end of the skill spectrum. While younger Canadians perform comparatively well, there are significant opportunities for improvement to increase the level of fundamental skills among all learners, as well as to grow the talent pool of top performers.

Quality interventions beginning in the pre-primary years are a significant factor in both of these endeavours, representing crucial long-term investments to develop a STEM-literate society. Strong foundations in STEM literacy (enabled by effective teachers, research-based pedagogical methods, and engaging instruction and curricular materials), coupled with support for early interventions that build on children's informal knowledge, are key aspects of developing a strong community of learners while challenging top students to excel academically. These skills form the basis for more complex STEM skills, from middle school through to post-secondary education (the latter of which is explored in Chapter 6).

The Panel agreed that high-quality resources and supports at each level are important for all students to develop their knowledge and skills, enable a range of future opportunities, and make informed choices. Considering that compulsory education in Canada is not governed by regular market forces, strong public investments are important for developing a STEM-literate society with the skills to adapt to an evolving labour market and an uncertain future.

6

Meeting Future Needs for Practical and Advanced STEM Skills: Post-Secondary Education, Employer-Sponsored Training, and Increasing Diversity

6 Meeting Future Needs for Practical and Advanced STEM Skills: Post-Secondary Education, Employer-Sponsored Training, and Increasing Diversity

Key Findings

The post-secondary education system is a key source of practical and advanced STEM skills. Half of all doctoral degrees in Canada are earned in STEM fields, and the number of these degree earners has been growing.

The number of STEM graduates is to some extent a useful indicator of supply. Individuals are guided by market forces and personal decisions. There is no single pipeline flowing directly from STEM credentials to STEM careers.

Employer-based training represents an important component of occupational and firm-specific employee skills development. Such training includes on-the-job learning, which is especially important during transitions from school to work; and ongoing opportunities for formal training and professional development.

Canada no longer tracks employer-based training data at the national level. Available data suggest that employees in Canada receive less workplace training than those in many leading European countries. This may limit the extent to which Canadian workers are able to gain experience and develop skills to improve efficiency and productivity, and it may limit employers' ability to fill their needs for skilled workers.

Flexibility in a range of education and training systems is important to equip the next generation of students with life skills and STEM skills. Some strategies, such as integrated learning, can bridge the divide between post-secondary education programs and ongoing employer-sponsored training initiatives. They can also empower students with the complementary skills demanded by employers that may help maximize the impact of practical and advanced STEM skills.

Canada is currently missing out on an important supply of skilled talent. Increasing the STEM participation of under-represented populations at all levels of education and occupation, including women and Aboriginal peoples, is an important strategy to ensure that all populations develop STEM literacy and to expand the supply of STEM-skilled individuals.

Meeting future demands for workers with practical and advanced STEM skills can be achieved in three ways: (i) entry from the domestic education system, (ii) improving the skills of current workers, and (iii) immigration (HRSDC *et al.*, 2008). This chapter looks at the first two sources of supply, examining how Canada can develop and maximize the knowledge and skills of individuals who continue their STEM education and training. The third source of STEM skills, immigration, is explored in Chapter 7.

As explained in Chapter 3, the number of post-secondary STEM graduates is not necessarily a useful indicator of supply. For example, while a STEM education is a prerequisite for a number of STEM occupations, only 39% of employed STEM-educated individuals end up working in STEM-intensive occupations in Canada. Similarly, non-STEM degree-holders are found in even the most STEM-intensive occupations. Observers have noted that the large proportion of STEM-educated individuals working in non-STEM professions may be attributed to the transferability of STEM degrees rather than an oversupply of STEM graduates (Carnevale *et al.*, 2011). The Panel deemed this to be an asset in the face of an unknown future. Additionally, the Panel suggested that because a degree of STEM is present in nearly every occupation (e.g., sales, management), individuals with STEM skills are valued by a range of employers. In pure labour market terms, it is usually inefficient to allocate resources to skills training that people will not use. However, through development of learning abilities and STEM competencies at the post-secondary level, individuals can increase their capacity to acquire skills required to pursue work that is of interest to them, and adapt to changing labour market circumstances.

The Panel agreed that beyond preparing individuals for their first job, the purpose of education is to prepare individuals for life — and a lifetime of potentially disparate careers. As presented in Chapter 4, complementary skills development is an important component of this. In addition to STEM at the post-secondary level, which includes academic programs, professional programs, and courses in continuing education, this chapter examines the extent to which employers are providing employees with the opportunities to develop occupationally specific skills. It also discusses the largely unrecognized STEM potential of under-represented populations, such as women and Aboriginal peoples.

6.1 POST-SECONDARY EDUCATION

In 2009, 6.7% of Canada's GDP was allocated to educational institutions, which is higher than the OECD average of 6.3% (StatCan, 2014e). A majority of Canadian investments in education are allocated to pre-primary, primary, secondary, and post-secondary non-tertiary education, rather than tertiary education. However, compared with the OECD average, Canada spends a smaller share of its GDP on the former and a greater share on the latter (StatCan, 2014e). In the fiscal year of 2012-2013, about 80% of higher education R&D (HERD)[27] expenditures were concentrated in natural sciences and engineering, and the remaining 20% in the social sciences and humanities (StatCan, 2014b). Investments in domestic training are essential for educating Canada's next generation, strengthening current capacities, and enabling an adaptive labour force. In general, preparation is provided through post-secondary institutions (colleges, universities, polytechnics), employer-based training, and government programs.

Overall, 64.1% of adults in Canada aged 25 to 64 have post-secondary qualifications (as of 2011) (StatCan, 2013f). 25.9% of adults hold a university degree at the bachelor's level or above, 21.3% have a college diploma, and 12.1% have a trades certificate.[28] About 1 in every 10 Canadians aged 15 or older holds a STEM credential (9.8%), and about 1 in 20 holds a STEM degree at the bachelor's level or higher (5.1%) (StatCan, 2013i) (Appendix B). Of Canadians with a university credential at the bachelor's level and above, 24.4% hold this credential in a STEM field (see Chapter 3 and Appendix B for other current data). This section looks at trends suggested by longitudinal data from 2001 onwards.

As depicted in Figure 6.1 (right column), a higher proportion of students graduate with non-STEM degrees than STEM degrees. This proportion has slowly and slightly increased over the past decade, which is not surprising considering that many large non-STEM professional programs are categorized as undergraduate programs (e.g., law, education, business, and medicine). Among STEM programs in the early 2000s, mathematics and computer sciences, engineering, and science produced relatively similar proportions of graduates. Throughout the decade, the proportion of engineering and science graduates remained stable, but the proportion of mathematics and computer sciences graduates slowly decreased (but it now appears to have stabilized).

Comparing graduates by education level, a minority of bachelor's degrees, compared with half of doctoral degrees, are earned in STEM programs. In contrast to the downward trend in mathematics and computer sciences graduation

27 HERD funding is derived from internal funding from the higher education sector, federal and provincial government sectors, the private non-profit sector, the business enterprise sector, and the foreign sector. Total HERD funding is the sum of direct sponsored research (university research funded by external organizations), direct non-sponsored research (time spent on research as a co-part of teaching), and the indirect costs of both (StatCan, 2011).

28 Of the 64.1% of Canadians with a post-secondary qualification, 4.9% indicated that they held a university certificate below the bachelor's level. However, Statistics Canada cautions that this category may have been overreported (StatCan, 2013f).

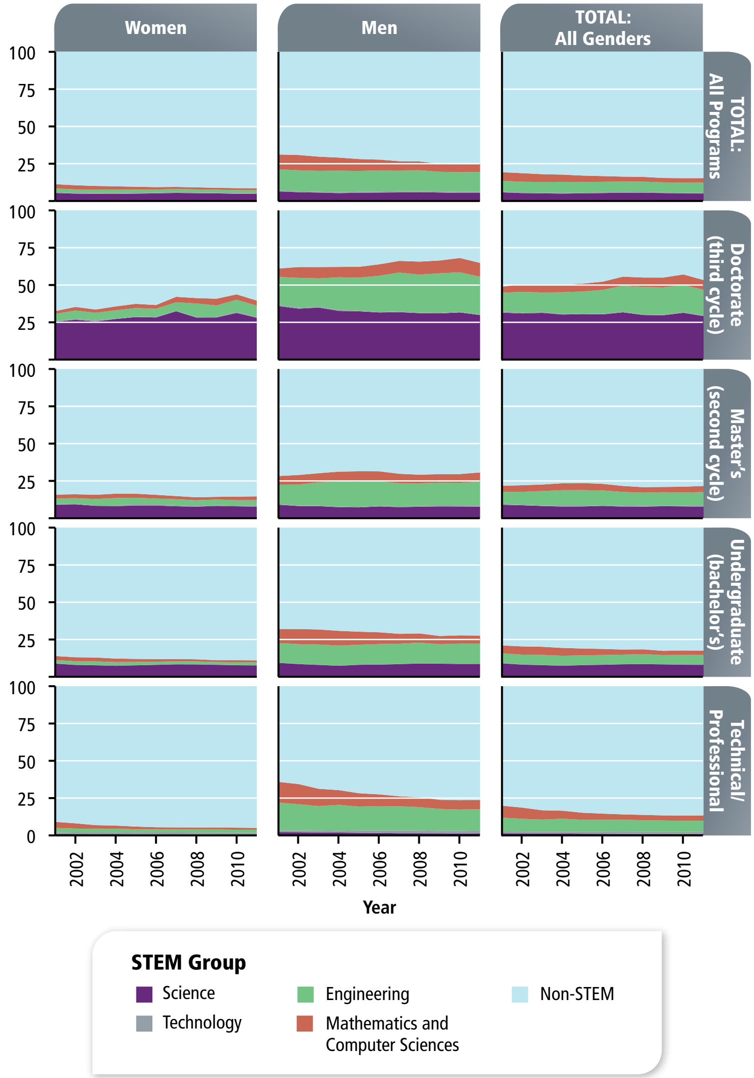
rates at the undergraduate level and in technical programs, a subtle increase is observed at the doctoral level. The proportion of graduates from STEM programs at the master's level has remained relatively constant since 2001.

Men are more likely than women to graduate from a STEM field. At each level of education, marked differences exist between the proportion of women and men graduates in STEM. Engineering programs are the most popular choice among men and science programs among women. The ratio of women to men graduates is the most balanced in science programs and at the doctoral level overall. The sheer volume of men graduates compared with women graduates renders the pattern depicted in the "men" column similar to the pattern in the "total" column.

The *number* of non-STEM graduates is also much greater than of STEM graduates. Figure 6.2 shows the rapid increase in the number of non-STEM graduates from 2000 to 2011, while the number of STEM graduates remained relatively constant (with small increases at a much slower rate).

There are, however, some interesting trends by level of education. Although doctoral degrees represent a small fraction of all degrees, and STEM degrees a smaller fraction still, the number of STEM doctoral graduates increased by about 50% from 2000 to 2011 (StatCan, 2014c). The number of doctoral degree earners in STEM and non-STEM programs was about the same in the early years of 2000, but the number of STEM graduates with PhDs began to outnumber and outpace non-STEM PhD graduates around 2005. It is unclear whether or not this trend will hold. In the same period, the number of STEM graduates with master's degrees doubled. Growth in the number of non-STEM master's graduates has been on a steep upward trajectory since 2001. By 2011, more non-STEM master's degrees were awarded than STEM master's degrees, by a ratio of about 4 to 1 (StatCan, 2014c).

While these data are informative, recall from Chapter 3 that only 39% of employed Canadians whose highest degree is in STEM end up working in STEM-intensive occupations (Table 3.3; Panel calculations using StatCan, 2014n). Similarly, some non-STEM graduates will work in STEM occupations. With this in mind, the Panel reiterated that there is no single pipeline flowing directly from STEM credentials to STEM careers. Thus, the number of STEM graduates is to some extent a useful indicator of supply, guided by market forces and individual decisions. As previously highlighted, the Panel concluded that Canada appears to have a well-functioning labour market, with no evidence of a current imbalance of STEM skills nationally. However, findings presented in the remainder of this chapter suggest that Canada could be doing more to maximize its STEM potential.

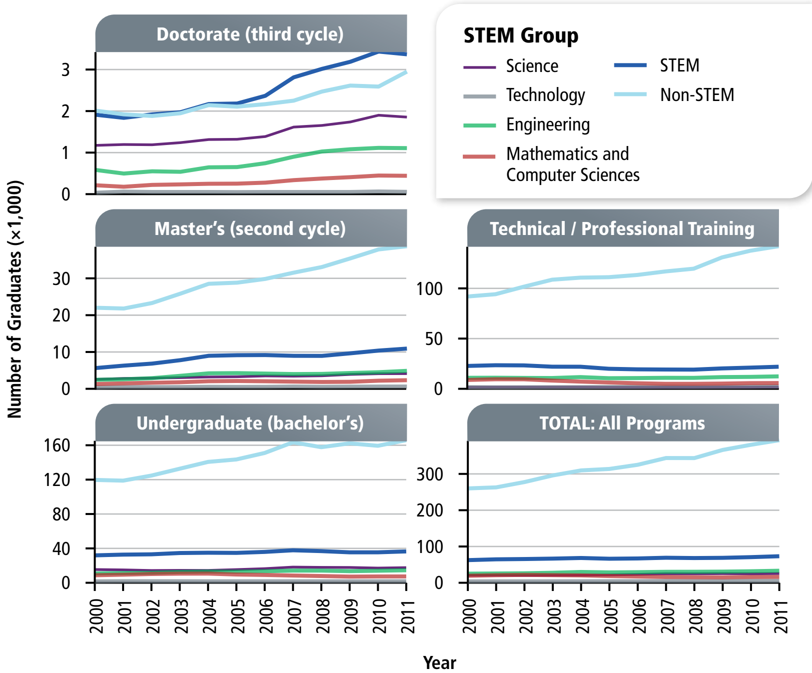


Data Source: StatCan (2014c) and Panel calculations

Figure 6.1

Proportion of Graduates by Program Type in Canada, 2001–2011

This figure shows the proportion of students who graduated from 2001 to 2011 from Canadian institutions in STEM and non-STEM fields.



Data Source: StatCan (2014c)

Figure 6.2

Number of Graduates by Program Type in Canada, 2000–2011

This figure shows the number of students who graduated from 2000 to 2011 from Canadian institutions in STEM and non-STEM fields.

6.2 EMPLOYEE TRAINING

In addition to educating new graduates, renewing and upgrading the skills of the current labour force is also critical. The specific nature of the required skills is widely contested, as is the extent to which employers perceive new graduates to have these skills and the role that Canada's post-secondary institutions and firms should play in teaching them (see CHE, 2014; Davidson & Soubry, 2014). The Panel highlighted that while this is not a new topic, some of the divergence between employer expectations and graduates' skills may be explained by a steadily increasing stream of post-secondary graduates combined with rapid changes in the world of work, such as technological transformations (Chapter 4), and growing expectations for immediate workforce preparedness (see CHE, 2014). At the core of these findings is the debate about who should be responsible for training the next generation of workers.

It is clear that adaptability is an asset that will help individuals respond to changing employment demands. The Panel agreed that this adaptability can be an outcome of quality Kindergarten to Grade 12 education (Chapter 5) as well as of post-secondary education. Post-secondary programs can also help students to develop the technical skills required for a given occupation. However, educational institutions alone cannot be expected to train students for the range of tasks that they may encounter in professional environments. Thus, echoing findings from others, the Panel also concluded that employers are a critical source of occupational and/or industry-specific training.

6.2.1 Employer-Sponsored Training

Economists understand human capital, or labour force skills, to be a major driver of economic performance and growth. As discussed in Chapter 2, common indicators of human capital measure the amount of formal education, but on-the-job training may be equally important to productivity (Acemoglu & Pischke, 1999). Evidence shows that wage returns to formal education are more stable than returns to job training, and not all job training is alike: some courses provide continuous long-term rewards, whereas others do not appear to increase wages (Haelermans & Borgans, 2011). However, a large body of literature highlights the benefits of job training: Haelermans and Borgans (2011) meta-analysis of 71 estimates found that the average training episode has a positive wage effect, at 2.6%. Evidence shows that training can also positively affect the productivity of firms (Dostie, 2010; Plesca & Summerfield, 2014). For example, Dostie (2010) found that each dollar invested in employer-sponsored classroom training yields a maximum of eight dollars in value added, although it is not clear how this return is allocated between the employer and employee. One of the mechanisms by which continuous training may enhance productivity is increased access to new knowledge, which in turn may increase a firm's propensity to innovate (Bauernschuster *et al.*, 2009; Dostie, 2014).

Since the 1970s, economists have understood general skills (such as education or occupational training) to be transferable among occupations or firms, whereas specific skills (such as firm-specific training) are not. Employees that receive training that is occupationally specific but transferable across organizations will likely be able to negotiate a higher market wage. If the training is organizationally specific, employees will not command a higher wage because the skills cannot be used elsewhere (Plesca & Summerfield, 2014). The Panel noted that compared with what is socially optimal, the threat of employee poaching may lead to firms underinvesting in occupationally targeted training. Thus, the extent to which employer-sponsored training enables adaptability and flexibility varies.

While post-secondary institutions have a role to play in developing individuals as productive members of society, so too do workplaces (see Box 6.1). Technological innovation, organizational changes in workplaces, ongoing R&D, and increasingly competitive marketplaces have bolstered demand for on-the-job training (Xu & Lin, 2009). The Panel also noted that short-term needs may also drive workplace training. Effective workplace training helps employees maintain and improve job-related skills, with positive impacts on productivity, innovation, and economic outcomes (CCL, 2007a, 2010). In turn, an individual's education and training may mitigate employment shocks and facilitate adaptability, serving as a preventative social policy measure. This adaptability is important for individuals' labour market success as well as overall market efficiency, especially during times of structural changes in the economy (Riddell & Song, 2009).

Box 6.1
Engineering in 2020: Experience and Training Required

A 2012 report for Engineers Canada presents scenarios for future labour market conditions that may affect the future of the profession in Canada. Key national trends reveal an imbalance that centres on an abundance of Canadians seeking engineering work, but lacking relevant Canadian and/or professional experience:

- There is an abundance of young engineering students and new graduates. By 2020, the number of new graduates entering the workforce is expected to be just under the total requirements of expansion and replacement demand. This cohort has yet to acquire the practical skills desired by employers.
- As the labour pool of young engineers increases, there is also an increase in foreign engineers arriving in Canada.
- An imbalance emerges as a significant number of Canadians and immigrants seek engineering work, but lack the experience desired by recruiters. At the same time, experienced engineers are retiring, taking valuable skills with them.

Requirements appear skewed towards replacing retiring workers with more than 10 years' experience, rather than creating new jobs related to expansion demands (which are primarily in western Canada). Demographic trends are expected to combine with other factors to develop tight markets for more experienced and specialized engineers, but weaker ones for new graduates. While these imbalances are not new, they become more acute as an increasing proportion of the workforce approaches retirement. Adaptations to mitigate the anticipated impacts include retaining older engineers longer, increasing employer-sponsored training for new graduates, closer communication with post-secondary institutions and programs, and increased flexibility and portability of engineering services across regions.

(PEA, 2012)

Employee training data were formerly tracked through Statistics Canada's comprehensive Workplace and Employee Survey (WES), the Adult Education and Training Survey (AETS), and the Access and Support to Education and Training Survey (ASETS). Results show that in 2005 (the final year for which complete WES results were collected), 59% of Canadian workplaces offered some form of classroom or on-the-job training. Comparatively, this placed Canada behind European leaders such as the United Kingdom (90%), Denmark (85%), Sweden (78%), and France (74%) (WES and Eurostat results cited in CCL, 2010). In Canada, the most common forms of training include new staff orientation and health and safety training. Advanced training (e.g., literacy and numeracy, managerial training) was offered much less frequently (CCL, 2010).

From 2002 to 2008 in Canada, employer support for educational endeavours decreased, but support for work training activities increased (Knighton *et al.*, 2009). AETS and ASETS results show that participation in formal job-related training for working adults[29] increased from 29% in 1997 to 36% in 2008 (StatCan, 2010). However, about one-third of Canadians still reported unmet training or education needs or wants as of 2008 (Knighton *et al.*, 2009).

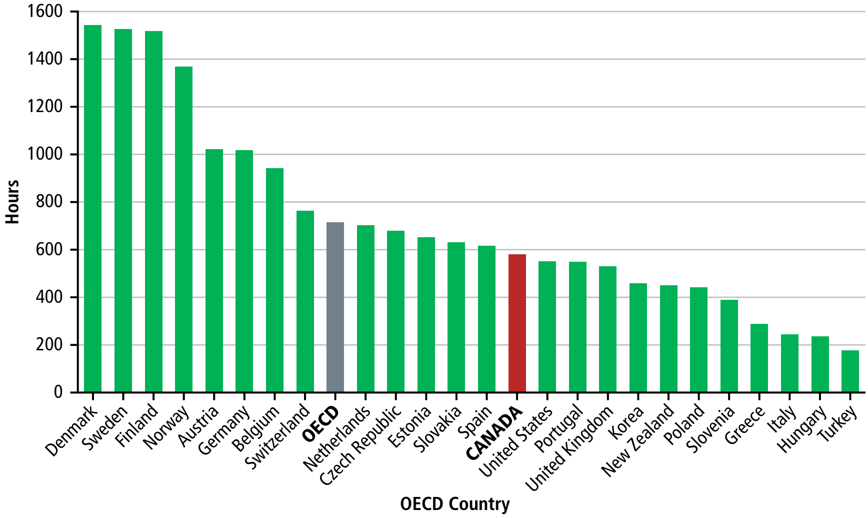
Comparable OECD data from 2008 show that participation rates in job-related non-formal education[30] in Canada (31%) are slightly higher than the OECD average (28%), yet only about half those of Sweden's (61%) (OECD, 2011a). Over the course of their working life, adults in Canada can expect to participate in 581 hours of job-related non-formal education, which is similar to the United States but about 20% less than the OECD average, and 62% less than the average across OECD leaders Denmark, Sweden, and Finland (OECD, 2011a) (see Figure 6.3).[31]

More recent evidence from the Conference Board reveals that direct learning and development expenditures were about $688 per Canadian employee in 2011, representing a 13% decrease since 2008, but nearly a 40% decrease since 1993 (Lavis, 2011; Stuckey & Munroe, 2013). Figure 6.3 indicates that Canadians can expect to receive slightly more training than their U.S. counterparts, but from 2006 to 2010 Canadian organizations reportedly spent an average of 64 cents on employee development for every dollar spent by U.S. organizations (Lavis, 2011).

29 Aged 25 to 64, employed at some time during the reference year.

30 Non-formal education may take place both within and outside educational institutions, and caters to people of all ages (OECD, 2011b).

31 Reference years 2008, 2005, and 2006, respectively.



Adapted from OECD (2011a)

Figure 6.3

Expected Hours Over the Working Life in Job-Related Non-Formal Education, OECD Countries, 2009

Data are from 2009 or most recent year. Reference periods range from 2005 to 2009. Since data were not available for all OECD countries, a selection is presented. According to the OECD, this includes all "organised, systematic education and training activities in which people take part in order to obtain knowledge and/or learn new skills for a current or a future job, to increase earnings, to improve job and/or career opportunities in a current or another field and generally to improve their opportunities for advancement and promotion" (OECD, 2011b).

A key factor in the extent to which workplace training is provided is firm size. WES results indicate that nearly all large firms in Canada (500 or more employees) offer formal classroom training, compared with 58% of small firms (20 or fewer employees) (CCL, 2010). The majority of studies focus on formal training,[32] which is easier to measure and interpret, but the many small and medium-sized enterprises (SMEs) tend to rely on informal training[33] (CCL, 2010; Kelly *et al.*, n.d.).

32 *Formal training* is generally delivered by educational institutions and provides individuals with critical professional skills. It can include workshops and seminars, and may involve obtaining a certificate or diploma. *Informal training* includes on-the-job training, which may be both firm-specific and transferable (Kelly *et al.*, n.d.). It may be undertaken to fulfil accreditation requirements (e.g., apprenticeships), develop new employees' skill sets, or update staff's existing skills.

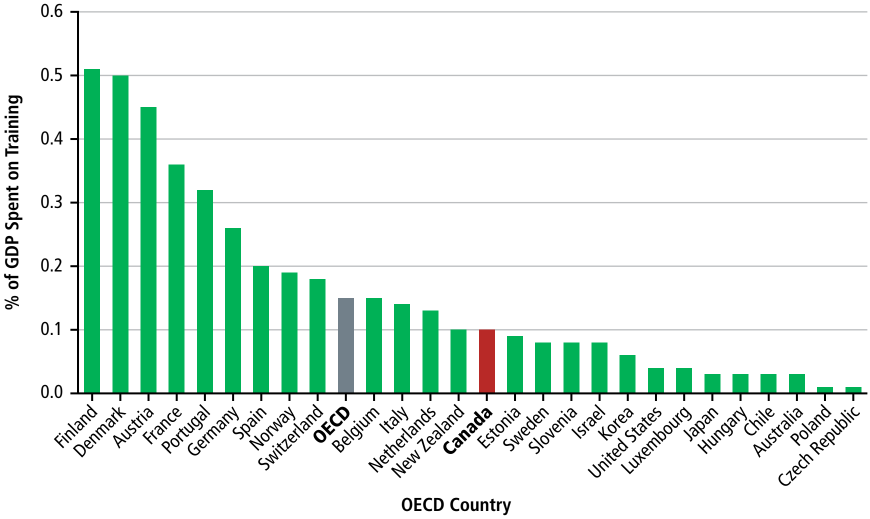
33 In a 2008 Canadian Federation of Independent Business survey of about 8,000 SMEs, 39% of SME owners indicated that they provide a mix of training types (down from 43% in 2002), whereas 45% provide informal training exclusively, 10% provide formal training only, and 6% do not provide any training (Kelly *et al.*, n.d.).

The Panel emphasized findings that others have also noted: more research is required to understand how employer training investments are shifting (McDaniel *et al.*, 2014) and whether there are differences by field (STEM and non-STEM). This would help to clarify and compare the extent to which employers are investing in employees with the extent to which they expect the education system to provide students with job-specific skills. Further, actions such as fostering a learning organization culture and developing collaborative networks are examples of under-studied yet potentially beneficial forms of employer-sponsored training.

While the mixed evidence indicates that some firms remain more committed to ongoing learning than others, some have observed that as concerns about skills gaps are increasing, employer investments in training are lagging (Stuckey & Munroe, 2013). Training costs, a lack of information on specific training requirements, and concerns about employee attrition and competitive poaching are cited as factors that inhibit workplace training; however, increasing the quantity and quality of employer-provided training has been identified as a critical investment in employee and organizational development (Miner, 2010; Stuckey & Munroe, 2013; CHE, 2014).

6.2.2 Government-Sponsored Training

Underinvestment in employer-sponsored training adds to the need for government training programs (Plesca & Summerfield, 2014). Plesca & Summerfield (Plesca & Summerfield, 2014) argue that the extent to which policy and public funds are directed towards public training programs will depend to some degree on how the goals of equity and efficiency are prioritized. Figure 6.4 shows that in Canada, a smaller share of the GDP is spent on publicly funded training compared with other OECD countries.



Reproduced with permission from Carey (2014); data from OECD Labour Market Programme Database

Figure 6.4

Publicly Funded Training Expenditures as a Share of GDP, OECD Countries, 2011

A number of federal skills development and training opportunities in Canada aim to help build a flexible and prepared workforce, including the Canada Job Grant;[34] the Apprenticeship Training Tax Credit;[35] the First Nations and Inuit Skills Link Program;[36] assessment, learning, and training supports for employers (ServCan, 2014a); the Youth Employment Strategy (ServCan, 2014b); and funding for organizations to strengthen fundamental literacy skills to address employability and workplace issues (ESDC, 2014b). Diverse provincial and territorial strategies also exist, many of which are supported by the Canada Job Fund.[37]

Quebec's *Act to Promote Workforce Skills Development and Recognition* is an example of a provincial lever to improve workers' qualifications and skills. Since 1995, Quebec has mandated that firms with a payroll exceeding $1 million must invest

34 Through this grant, the federal government provides employers with up to $10,000 to train each worker. Employers are expected to contribute up to $5,000. These funds supplement training, tuition, and materials (Mas, 2014).

35 This helps firms to employ apprentices in skilled trades during the initial three years of an apprenticeship program (ServCan, 2014a).

36 This program provides funding to First Nations and Inuit employers to create youth-oriented development programs (ServCan, 2014a).

37 This federal funding, formerly known as bilateral Labour Market Development Agreements and Labour Market Agreements, enables provinces and territories to design and deliver employment programs (ServCan, 2014a).

at least 1% of payroll in employee training, or pay an equivalent amount into the provincial skills development fund (RQ, 2012; GQ, 2014). The OECD has identified such financial incentives and tax policies to encourage individuals and employers to invest in education and training as promising (OECD, 2012a). Industry and educational leaders have suggested that policy-makers could augment training opportunities by embracing a broad definition of skills, promoting adaptability, collaborating with partners in business and post-secondary education to collect better labour market data, and investing in student internships and international exchanges (Davidson & Soubry, 2014). A wide spectrum of part-time and full-time adult learning opportunities can help individuals progress in their careers as well as adapt to changing labour force demands, such as work-related employee training, formal education, fundamental literacy training (Chapter 5), and labour market training programs for job seekers (OECD, 2012a).

6.3 FLEXIBILITY IN EDUCATION AND TRAINING PROGRAMS

While data from Chapter 3 suggest that STEM degrees in and of themselves enable flexibility, the Panel added that flexibility in a range of education and training systems is required to sufficiently equip the next generation of students with the STEM skills that they need as workers and as members of society. Some strategies, such as experiential learning, can bridge the divide between post-secondary education programs and employer-based training initiatives (Kramer & Usher, 2011). Evidence also suggests that they can help students develop the complementary skills that are sought after by employers (OECD, 2012a) and play a role in activating STEM skills. This section highlights three examples of learning strategies aimed at these goals. For these goals to be achieved, collaboration and effective partnerships among post-secondary institutions, government, industry, and community organizations are important (Sattler & Peters, 2012). Considering the increasing number of programs and courses that are delivered online, as well as the self-appropriation of learning, the Panel also identified digital inclusion and universal broadband access as enablers of flexibility and options in education and training (see BCDD, 2014).

6.3.1 Work-Integrated Learning

Internships, co-operative (co-op) education, field placements, and summer jobs are helping students develop critical complementary and specialized skill sets, while preparing them for careers (Kramer & Usher, 2011; Sattler & Peters, 2012; WMI, 2012; Smith & Lam, 2013). Compared with purely school-based learning, integrative programs can assist with the development of technical skills as well as complementary skills. Skills such as teamwork, negotiation, and communication can be gained through the "real-world" experience that integrative programs offer (OECD, 2012a).

Results from a 2014 CCCE survey indicate that over 25% of large Canadian employers expect entry-level hires to have already worked for a minimum of two years (CCCE, 2014). The Panel expressed concern about this threshold, noting that work-integrated learning programs, which combine academic studies with work experience (see Box 6.2), may help students navigate the labour market upon graduation. With quality standards maintained by the Canadian Association for Co-operative Education, participation in co-op and work-integrated learning programs significantly increases student satisfaction ratings, helps students transition into the workforce, and is linked to positive employer perceptions and higher starting salaries (Sattler & Peters, 2012; CCCE, 2014; Sattler & Peters, 2014). A multi-year HEQCO study reveals that 68% of college students and 48% of university students in Ontario have participated in work-integrated learning programs, and that STEM and health science students were particularly likely to be involved (Sattler & Peters, 2014). While there are a range of benefits, costs are associated with administering such programs (Peters, 2012). Analyses of what relative proportion of these costs should be financed by students, employers, and post-secondary institutions would be useful.

Box 6.2
Canadian Models for Co-Operative Education

With the largest post-secondary co-op program of its kind in the world, Ontario's University of Waterloo's (ON) co-op model has spread to more than 100 colleges and universities across the country (UW, 2014a): Of undergraduate programs, 80% offer co-op options. Students may be placed with one of 5,200 employers around the globe to gain valuable international experience. Co-op students can expect to gain a minimum of 16 months of work experience, and to generally have smaller student loans and receive higher earnings upon graduating compared with graduates who did not participate in a co-op program (UW, 2014b). While on a work term, students apply learning objectives, participate in a professional development course to help hone workplace skills, and complete work reports and performance evaluations (UW, 2014c). As the first Quebec institution to offer co-op programs, the Université de Sherbrooke (QC) places 40% of its undergraduate population in positions in one of 1,000 organizations in Canada and internationally (US, 2014). By engaging in productive paid work in addition to valuable classroom time, students gain a broad set of skills and experiences to help prepare them for work and life, and employers gain an efficient means of identifying and integrating future employees.

6.3.2 Continuing Education

The Panel agreed that a flexible education system also includes support for continuing education for adults. As the labour market evolves, workers will require short-term options for STEM skills development. Continuing education programs provide responsive, customized training in various formats, enabling individuals to build on current competencies or develop entirely new ones (see Box 6.3). Such programs are generally delivered through school boards, colleges, and universities. Ranging from classroom-based courses to distance-based online programs, learners stand to gain short- and long-term benefits. However, the Panel noted that in Canada, education funding is organized around formal credentials. As a result, programs outside of this scope, such as continuing education programs, are generally not subsidized. Thus, access to and support for continuing education remains limited. Organizations working to develop a greater role for post-secondary institutions to respond to Canada's requirements for lifelong learning, training, and retraining include the Canadian Association for University Continuing Education, the Ontario Council for University Lifelong Learning, and the Atlantic Provinces Association for Continuing University Education.

Box 6.3
Massive Open Online Courses and the Future of Education

Around 2008, the term *MOOCs* emerged to describe massive open online courses. Since then, they have rapidly gained popularity and evolved to offer a broad scope of courses. Some MOOCs run on open-source learning platforms and are directed by academics (e.g., Alberta's Athabasca University), while others are free online versions of lectures owned by private enterprises (e.g., edX, Udacity, Coursera, and FutureLearn). Some MOOCs offer accredited learning; micro-credentials and certificates can be obtained following successful course completion. In a literature review on the topic, the U.K. Department for Business, Innovation & Skills found that consensus points on MOOCs include their importance, popularity, and expansion, while points of contention include sustainability and the value of the learning that they promote (BIS, 2013). While the future of MOOCs is yet to be revealed, they may have the potential to disrupt, challenge, and complement traditional models of higher education.

6.3.3 Apprenticeships

In addition to education in a STEM field at the diploma or certificate level, apprenticeship represents one forum through which valuable practical STEM skills can be gained. A small but growing body of research on Canadian apprentices and apprenticeship programs is emerging (Laporte & Mueller, 2012). Apprenticeship is a workplace-based training program that teaches the skills necessary to complete tasks in the trades according to industry standards. About 80 to 85% of an apprentice's time is spent on the job (including about 1,600 hours of supervised experience), and 15 to 20% on technical training at a college, union training centre, private training centre, or online (CCC, 2013; CAF, 2014). Upon completion of a two- to five-year program, certification exams may be written (CCC, 2013). About 90% of all registered apprentices in Canada are represented by the Red Seal Program, which ensures common national standards, thereby promoting mobility (PPF, n.d.).

In contrast to approaches in Germany, Switzerland, and Austria, apprenticeship in Canada is mainly geared towards adults: in 2012, only 6.6% of those registered in apprenticeship programs were under the age of 20 (StatCan, 2014a). Considering this, some argue that the Canadian system does not currently facilitate the transition between high school and the labour market (Lerman, 2014). A strong majority of registered apprentices in Canada are men (around 80%), which has remained unchanged over the course of recent decades (StatCan, 2013j).

Enrolment in registered apprenticeship programs in Canada increased by 120% from 1995 to 2007, although completion rates over the same period increased by only 43% (Laporte & Mueller, 2011). The number of certificates granted to registered apprentices increased by 19% from 2008 to 2012 (StatCan, 2014j). Data on completion rates are significant in and of themselves, but also considering that apprenticeship completers have higher hourly wages than those who discontinue their studies (Laporte & Mueller, 2012). Many trades require STEM skills, but inadequate fundamental numeracy and literacy skills are cited as one of the reasons for low completion rates (CAF, 2011; CCC, 2013) (as presented in Chapter 5).

While practical STEM skills as a concept are considered throughout this report, the Panel followed Statistics Canada's approach to defining STEM fields of education for more in-depth empirical analyses (recall Chapter 1). The fields of study used to classify Canada's post-secondary programs into STEM or non-STEM categories were found to be a poor fit with trades and apprenticeships. As a result, the Panel did not consider detailed data on individuals with this training, but they are included in higher-levels of analyses when possible (Chapter 3). All classification systems have limits; this one does not capture all STEM skills in the Canadian population or all fields that use or apply some form of STEM skills or knowledge.

6.4 LABOUR FORCE GROWTH THROUGH DIVERSITY

As previously discussed, strengthening the competencies of students, recent graduates, and those already in the workforce is important for Canada to meet current and future STEM skill requirements. Another aspect of the equation is widening the pool from which to draw talent. Canada's top researchers and innovators are needed to help develop Canada's social and economic potential. By attracting individuals with diverse perspectives, experiences, and ideas, a wider talent pool can reveal deeper assets. The majority of this section is focused on two under-represented populations in STEM: women and Aboriginal peoples (see Table 6.1). Evidence points to a range of factors that affect representation by field of study, occupation, and rank, ranging from personal preferences to discrimination and structural barriers (NAS, 2007; Hill *et al.*, 2010; CCA, 2012b; Actua, 2014). Overall, the implications of these disparities are costly for society, science, and innovation. Such disparities are a signal that Canada may be missing out on important aspects of productivity and innovation: maximizing the full potential of human capital.

Table 6.1

STEM Education and Employment in Canada by Gender, Immigrant Status, and Aboriginal Identity, 2011

	Total	Women % of Total	Immigrants % of Total	Aboriginal % of Total
Population aged 25–54	14,044,940	51.1	24.5	3.9
Post-secondary credential	9,340,495	52.5	26.1	2.5*
Post-secondary credential in a STEM field	1,814,075	29.6	39.9	1.4*
Post-secondary credential in a STEM field and employed in a STEM-intensive occupation	606,520	18.9	37.5	N/A
% of those with a STEM credential employed in a STEM-intensive occupation	*38.9%*	*26.9%*	*39.1%*	N/A

Data Source: StatCan (2013a, 2013i, 2014n) and Panel calculations

Totals represent all Canadians aged 25 to 54. Statistics that are presented at the aggregate level can hide important differences. In some cases, it is important to look at the data more closely. As demonstrated in this table, participation in STEM education and occupations varies by a number of socio-demographic variables. For example, while 52.5% of individuals with a post-secondary credential are women, only 29.6% of those in a STEM field are women. Of this group of women, only 18.9% are employed in a STEM-intensive occupation. As a result, the percentage of women with a STEM credential who are employed in a STEM-intensive occupation is 26.9% (see Table 3.3).

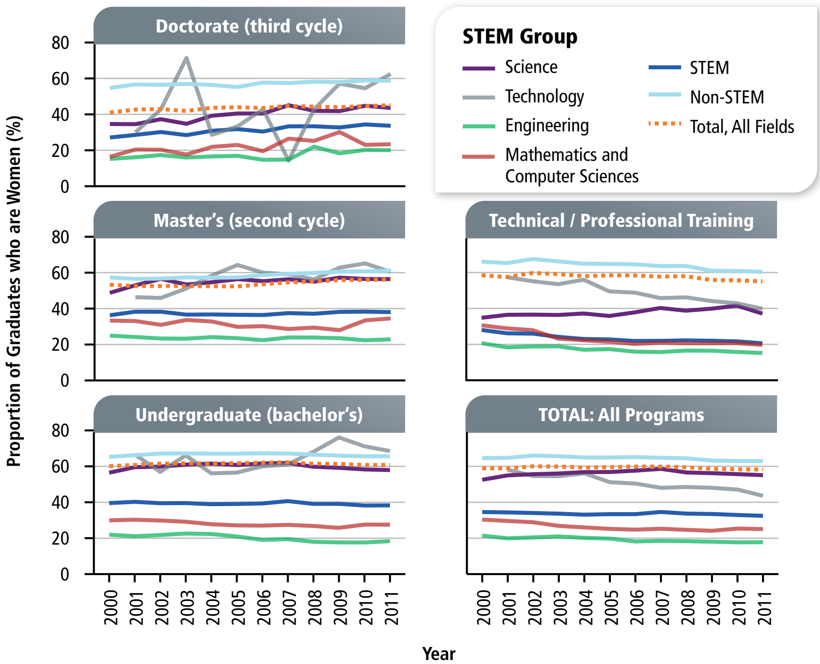
* Not including trades and apprenticeships.
N/A = These data are collected, but are not publicly available.

6.4.1 Women in STEM

Chapter 3 highlighted one of the most obvious disparities in STEM: the disparity between women and men, which is well documented as a serious social and economic concern (see Powell *et al.*, 2004; NAS, 2007). Women have made rapid gains in post-secondary education in Canada to the point that women now outnumber men in undergraduate and master's programs, and are close to parity with men at the doctoral level overall (AUCC, 2011; CCA, 2012b). However, major gender differences exist within fields of study. Women now significantly outnumber men as students of the humanities, social sciences, and education, as well as the life sciences, but the opposite is true in the physical sciences, computer sciences, engineering, and mathematics (CCA, 2012b). Men are more likely to graduate in a STEM field than women (recall Figure 6.1). This is especially true at the doctoral level and in mathematics and computer sciences as well as engineering programs in general. Similar proportions of women and men earn science degrees.

Figure 6.5 shows that for all program levels and fields combined, the gender balance in STEM has remained relatively unchanged from 2000 to 2011 (see total STEM group in "Total: All Programs" chart). However, despite gains in STEM subjects in earlier decades (see Appendix B), these data reveal a downward trend in the proportion of women graduates with STEM degrees in Canada, especially in technology. Science programs remain an exception.

All doctoral programs are slowly showing signs of increasing proportions of women, but, with the exception of science fields again, the proportion of women decreased in all technical and professional training programs over the period (StatCan, 2014c). At the technical and professional training level, the proportion of women graduates from technology programs significantly fell. Conversely, the proportion of women graduating with technology degrees at the undergraduate, master's, and doctoral levels has strongly increased since 2000. However, women's overall numbers in these fields are so small that the increases are not reflected in the overall totals (see "All programs").



Data Source: StatCan (2014c) and Panel calculations

Figure 6.5

Proportions of Graduates of Canadian Institutions who Are Women: STEM and Non-STEM Programs, 2000–2011

Dating back to 2000 (2001, in the case of technology programs), this figure depicts the proportions of STEM and non-STEM graduates of Canadian institutions who are women. Note that while the proportion of women in technology programs at the university level is relatively high compared with in other programs, the overall number of women with a technology degree is relatively low compared with other programs (the same is true for men) (see Appendix, Table B.1). This may explain some of the volatility observed in enrolment in technology programs at the doctoral level.

Further differences exist within each of these STEM programs, revealing areas where women are making inroads, as well as areas where critical mass has yet to be achieved. In 2009, only 22% of civil engineering undergraduate students were women, yet women accounted for 40% of undergraduates in environmental engineering (CCA, 2012b). Similarly, mathematics and computer sciences data are commonly presented together, but a closer look reveals that in 2008 women earned 44% of undergraduate degrees in mathematics and statistics, but only 15% of degrees in computer and information sciences and support services (AUCC, 2009). In combination with gender, a number of other socio-demographic variables are relevant to this discussion (see Box 6.4).

Box 6.4
STEM Degrees by Gender, Age, and Citizenship

Women are often presented as a homogenous group in comparison to men, but such analysis tends to hide differences that lie at the intersection of variables. For example, young immigrant women aged 25 to 34 are twice as likely to possess a STEM degree than their Canadian-born cohorts (23% versus 13%) (Hango, 2013). Differences also exist by field. Among STEM degree-holders, more young immigrant women than Canadian-born women have a STEM degree in engineering (28% versus 17%) as well as in mathematics and computer sciences (26% and 10%, respectively) (Hango, 2013). Chapter 7 describes this in greater detail.

Age is another variable that intersects with gender. Young Canadian women (aged 25 to 34) have a higher share of STEM degrees (39%) than women aged 55 to 64 (23%), indicating that the gender balance is shifting (StatCan, 2013j). The Panel agreed that this is encouraging, although previous research has found that time alone is unlikely to be enough to achieve gender parity (CCA, 2012b).

Gender disparities in STEM in Canada become more pronounced at the professional level. This is similar to in the United States, where women held 24% of STEM jobs in 2009 (Beede *et al.*, 2011).[38] This share, which has not changed in a decade, is higher than in the United Kingdom (13%) (Bocherby & Buckner, 2012).[39] The figures for Canada vary by sector (recall also Tables 3.1 and 3.2):

- Of women in academic STEM[40] research careers in 2008–2009, 24% were assistant professors, but only 9% were full professors (CCA, 2012b).
- In the advanced technology sector, women comprise just 24% of the workforce, 17% of whom are in core technology roles. Even fewer are in managerial positions (CanWIT, 2014).
- For the past decade, women's involvement in the ICT sector has remained at around 25% (Wensley, 2013). Among the 10 largest public ICT corporations in Canada, women represented about 16.5% of board members in 2013 (21 out of 127). This is similar to the Canadian average, but nowhere near critical mass (generally understood to be around 30%) (Wensley, 2013).[41]
- Notably, the proportion of STEM-educated women working in STEM-intensive occupations (26.9%) is lower than the proportion of men (43.6%) (Panel calculations based on StatCan, 2014n).

In addition to these low figures, attrition rates are a problem. Based on data from 28 international focus groups and four surveys, a U.S. Center for Work-Life Policy report shows that 52% of highly qualified women quit their private-sector science, engineering, and technology (SET) jobs (Hewlett *et al.*, 2008). Of these women, 48% moved on to SET jobs outside of the corporate sector, and 52% abandoned their training. Reasons for leaving include "extreme work pressure" (39%), "hostile macho culture" (38%), and "compensation" (27%). Among all women in SET, 63% reported experiencing sexual harassment on the job and 45% lacked mentorship; 44% of women in engineering and 38% of women in technology reported feeling isolated (Hewlett *et al.*, 2008). Similar challenges have been identified across a wide body of research examining the dearth of women in STEM careers (NAS, 2007; Cukier, 2009; CATAWIT, 2010; Orser *et al.*, 2012).

38 In this report, which is based on American Community Survey data, STEM jobs include professional and technical support occupations in the fields of computer sciences and mathematics, engineering, and life and physical sciences. Three management occupations are also included.

39 Health occupations are included in this particular definition of STEM.

40 In this case, STEM includes physical sciences, computer sciences, engineering, and mathematics.

41 If small and medium-size ICT firms were included in this figure (of which there are many), it would be much lower. Across all sectors, the number of women on boards declines significantly for smaller public companies.

Challenging some aspects of corporate culture and empowering women to enter and upwardly progress in the STEM workforce will continue to be an important aspect of developing Canada's STEM skills capacity — as will collecting the appropriate data required to track progress. Women have the capability and drive to succeed in STEM, and actions to mitigate systemic challenges have revealed positive results in terms of women's participation in STEM (see Box 6.5).

Box 6.5
Promoting Girls and Women in STEM Education and Careers

The Council of Canadian Academies' report of the Expert Panel on Women in University Research suggests that strategies to increase the number of women in research careers include multi-level, multi-stakeholder programs, policies, and practices that support girls and women as students and as members of the labour force. These may be enacted by governments, research councils, schools, post-secondary institutions, advocacy groups, the private sector, and non-profits. While no single option can be recognized as the perfect solution, responses may range from interventions that begin in primary school, such as engaging girls early, teaching about the many applications of science, providing hands-on learning experiences, role models, and inclusive teaching strategies. Information about the required steps to achieve future educational and career goals is important in high school, and mentorship and peer support programs appear particularly important at the post-secondary level. Other valuable actions include challenging stereotypes and demystifying the work of STEM professionals, especially in fields where women are strongly under-represented (Frize, 2009; Hill *et al.*, 2010). At the career level, inclusive working cultures are key, and may include family-friendly policies such as accessible child care, flexible models of career progression, bias-free recruitment training, targeted grants, and sponsorship initiatives (CCA, 2012b).

6.4.2 Aboriginal Peoples in STEM

Indigeneity is another factor of particular relevance in the Canadian context. The social, economic, and health and wellness-related effects of Canada's history of colonial policies towards Aboriginal peoples continue to resonate today, with noticeable effects in educational outcomes (Loppie Reading & Wien, 2009). Aboriginal Peoples Survey data show that compared with 89% of non-Aboriginal people, 72% of off-reserve and 42% of on-reserve First Nations people,[42] 42% of Inuit, and 77% of Métis aged 18 to 44 had a high school diploma in 2011 or 2012

42 Data are available for individuals aged 20 to 24 only.

(Bougie *et al.*, 2013; Richards, 2014).[43] About half of on-and off-reserve Aboriginal people[44] had a post-secondary qualification in 2011 compared with two-thirds of non-Aboriginal people (StatCan, 2013g). In the same year, the total working-age Aboriginal population with a university degree was about 10%, compared with 26% for the non-Aboriginal population (AANDC, 2013).

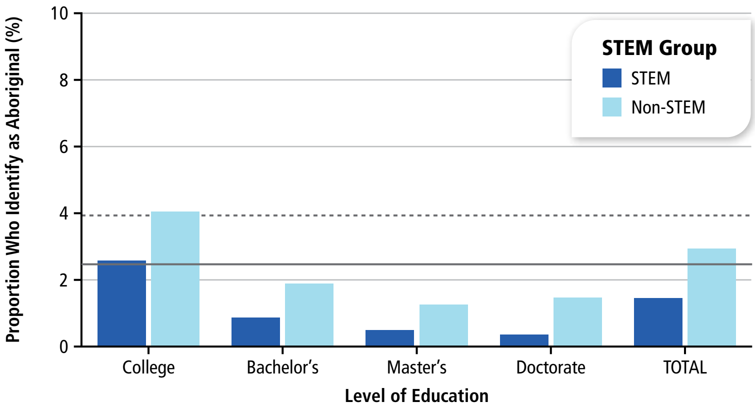
Representing about 3.7% of the adult population, just 2.6% of all people with post-secondary credentials in Canada are Aboriginal (StatCan, 2013c) (see Appendix B). In general, Aboriginal people, especially men, are under-represented in STEM fields, particularly at the post-graduate level. Aboriginal people are more highly represented among those with a college certificate than among graduate degree-holders, and in non-STEM programs compared with STEM programs (see Figure 6.6). These differences have largely persisted since 1996 (StatCan, 2014k) (see Appendix B). Among STEM degree-holders, a higher proportion of women than men identify as Aboriginal (StatCan, 2014n). Aboriginal representation among those with a post-secondary credential did increase from 1996 to 2006, except at the graduate level (master's and doctorate).

At the bachelor's level, the proportion of STEM degree-holders who identify as Aboriginal is higher among younger cohorts (the proportion is higher for 25 to 34 year-olds, and lowest for 45 to 54 year-olds) (Panel calculations based on StatCan, 2014n). However, Aboriginal people are greatly under-represented among those with earned doctorates, with less than 1% of STEM degree-holders and less than 2% of non-STEM degree-holders identifying as Aboriginal (see Appendix B). Overall, although a growing proportion of college graduates identify as Aboriginal, they continue to be under-represented in STEM fields, particularly at higher levels of education (see Figure 6.6).

The quickly growing Aboriginal youth population in northern Canada represents an increasingly educated and readily available workforce. A knowledge synthesis project by Abele and Delic (2014) analyzed the mismatch between the number of northern Aboriginal youth without paid employment and northern employers who are grappling with methods to develop skilled and sustainable local workforces. Across northern Canada, Aboriginal youth unemployment rates are the highest in Nunatsiavut (northern Newfoundland and Labrador), reaching 56.2% among young men and 23.5% among young women. While more research is required on labour market outcomes, evidence suggests that barriers to participation include non-completion of school, early parenthood, and overemphasis on

43 At 58%, the rate of incomplete high school studies among young (aged 20 to 24) First Nations people living on-reserve is particularly high. Unlike their off-reserve counterparts, this rate has declined little since 2006 (Richards, 2014).

44 About 5% of reserves were incompletely enumerated in the 2011 NHS.



Data Source: StatCan (2013a, 2014n) and Panel calculations

Figure 6.6

Proportion of STEM Graduates who Identify as Aboriginal in Canada, by Education Level, Aged 25 to 54, 2011

This figure includes all individuals aged 25 to 54 in Canada with a post-secondary degree (college certificate, bachelor's degree, master's degree, doctorate) in 2011. The dotted horizontal line indicates the proportion of the population (aged 25 to 54) who identify as Aboriginal, while the solid grey line indicates the proportion of those with a post-secondary credential (among those shown) who identify as Aboriginal. Bars below the solid line indicate groups where Aboriginal people are relatively under-represented (e.g., among university graduates at all levels), while bars above the line indicate groups where Aboriginal people are relatively overrepresented (e.g., among college graduates).

distance-limited employment opportunities (Abele & Delic, 2014). The authors contend that beyond programming that attracts youth into resource sector jobs, improving access to post-secondary education would improve the range of available career trajectories. Further, diversity across and within northern regions necessitates labour force planning and programming sensitive to local contexts and needs (Abele & Delic, 2014).

While significant efforts to address disparities in achievement have been undertaken provincially and federally, challenges clearly remain (CAP, 2010). Beyond broader, structural hurdles that exist for Aboriginal peoples and communities across Canada, barriers to science learning include the lack of Aboriginal mathematics teachers and role models, the gap between Western scientific knowledge and traditional knowledge systems, and a lack of culturally appropriate teaching strategies that account for Indigenous knowledge and pedagogy (Berkes, 2008; CAP, 2010; Hatcher & Bartlett, 2010). Evidence indicates that it is critical to address these challenges to mitigate the serious disparities in Aboriginal educational outcomes: inclusive curricula and culturally competent teaching that account for diverse ways of knowing are recognized as important tools for student empowerment and achievement (Hatcher & Bartlett, 2010). The Panel also identified engaging Aboriginal youth in positive, relevant, hands-on STEM programs that bridge traditional knowledge and Western science as a proactive strategy to increase involvement.

In terms of employment, the federal Aboriginal Skills and Employment Training Strategy fosters partnerships with the provinces, territories, and the private sector; supports demand-driven skills development; and helps Aboriginal peoples to find and retain employment (ESDC, 2014d). An evaluation of its precursor, the Aboriginal Human Resources Development Strategy (1999–2010), found that its programs and services helped participants to respond to employment challenges and overcome employment barriers, such as a lack of basic education, literacy, and job skills (HRSDC, 2009a, 2009b). Informants indicated that such services have improved clients' access to and use of labour market programs, and generally have led to employment and increased self-confidence (HRSDC, 2009a). The need to increase partnerships with the private sector was highlighted as an area for improvement. Land claims agreements-based Aboriginal employment plans and employer-mandated Aboriginal employment requirements and training programs represent other methods of increasing sustainable employment options.

6.5 CONCLUSION

Beyond building fundamental skills for STEM among all learners, post-secondary STEM education and workforce training play a critical role in meeting future demand for practical and advanced STEM skills. Universities, colleges, and polytechnics are charged with the challenge of preparing individuals for life, but also for participation in the labour market. STEM graduates, like all graduates, may have several careers throughout their lifetime — some of which do not even exist yet. However, many employers seek new hires who already have experience and targeted skill sets. This tension highlights the question of who is responsible for training the next generation of workers.

Recognizing the importance of educating students with a strong base of theoretical and technical skills, coupled with the broader, complementary skills that augment adaptability and are sought by employers, post-secondary institutions (sometimes in partnership with industry and governments) offer a range of flexible programs that respond to student and employer needs. Improvements and expansions in work-integrated learning, continuing education programs, and apprenticeships can bridge the divide between education and work, and represent important developments for students, industry, and society.

Educational institutions alone cannot be expected to train students for the range of specialized tasks that they may encounter in professional environments. Canadian employees, however, receive less workplace training upon graduating from school than employees in many leading countries in Europe. This has negative implications for workers and firms: workers need to gain experience and develop specialized skills to improve their own efficiency and the productivity of their employers. The underinvestment in employer-sponsored worker training emphasizes the need for government training programs to improve equity and provide opportunities for skills development.

Finally, to capitalize on Canada's STEM potential, it is vital to increase diversity among the population of STEM-skilled individuals. Equal opportunities do not necessarily result in equal outcomes, but significant differences in outcomes can be indicative of inequalities in opportunity. A wider pool of excellence can confer economic, social, and scientific benefits, such as a greater supply of human capital through increased labour force participation, making the most of prior educational investments, decreasing economic disparities, enhancing Canadian society's intellectual milieu, exemplifying equality, and accessing a wider range of knowledge perspectives. Opportunities for policy responses to increase the reach of Canada's STEM capacity exist at multiple points, but early interventions to support and expose diverse learners to a range of future education and career options have been identified as particularly critical.

7

Meeting Future Needs for Advanced STEM Skills: Immigration and the Global Market

7 Meeting Future Needs for Advanced STEM Skills: Immigration and the Global Market

Key Messages

STEM skills are globally transferable.

Beyond economic benefits, immigration has benefits for society, such as new perspectives, cultural knowledge, and enhanced social capital. Immigrants trained in Canada can help build bridges with their country of origin.

Research suggests that in addition to exerting a disproportionate impact on innovation, STEM-skilled immigrants generate significant spillover benefits for local workers in the form of increased wages.

Immigrants are a major source of STEM skills for Canada, representing about 50% of all STEM degree-holders. Difficulties in appropriately connecting skilled immigrants to the Canadian labour market impede the extent to which these skills can be activated. This is demonstrated by immigrants' higher unemployment and lower employment rates relative to Canadian-born STEM degree-holders.

Over 60% of international doctoral students in Canada graduate from STEM programs. Attracting and retaining international students is an example of how domestic education and immigration can be complementary assets in developing a knowledgeable and flexible workforce. Coordinated, collaborative action on behalf of the relevant federal and provincial actors is key to achieving this goal.

Canada's current immigration policy is closely tied to labour market needs. Immigration policy can be adjusted to respond to specific labour shortages in certain occupations. However, immigration programs to address short-term needs may undercut the incentive for firms to train workers, and for workers to invest in developing their skill sets.

In Canada, emigration is more than offset by immigration. Bidirectional flows of skilled labour increase international connections through "brain circulation."

This is the third and final chapter that addresses how Canada can meet future demands for STEM skills. Recall that Chapter 5 discussed the importance of empowering all learners with foundational STEM skills, and Chapter 6 explored the value of practical and advanced STEM education and training. This chapter investigates immigration as a factor affecting Canada's supply of individuals with advanced STEM skills, as well as the roles of immigration and emigration in the global skills market. Overall themes include the positive externalities associated with STEM-skilled immigrants, immigration as a tool for long-term sustainability, and emerging opportunities in the global market for STEM skills.

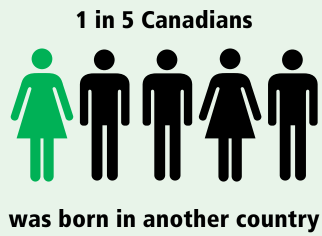
7.1 IMMIGRATION AS A SOURCE OF STEM SKILLS

For much of the 20th century, Canadian immigration policy was oriented towards economic goals and nation-building such as the settlement of the West, completion of railways, development of the natural resources sector, and creation of the manufacturing industry (Green & Green, 1999). Immigration policy was often used as a tool to encourage long-term growth and respond to short-term labour market needs, two goals that are not necessarily mutually exclusive (Green & Green, 1999). Reforms of the 1960s ended the discriminatory practice of distinguishing among "preferred," "non-preferred," and "excluded classes" of prospective new Canadians, and witnessed the introduction of the points system (see Box 7.1) (Triadafilopoulos, 2013). These changes built the foundations for the enactment of a new *Immigration Act* (1976). The Act represented a significant shift in immigration legislation, away from policy primarily shaped by economic aims towards one based on three main pillars that remain today (to varying extents): family reunification, humanitarianism, and a strong economy (Green & Green, 1999). Until the end of the 1980s, immigration was characterized by low inflows during economic downturns and large inflows aimed at specific goals in stronger economic times. In the 1990s, immigration began to be used to change the Canadian workforce, with the goal of rendering it more skilled and adaptable (Green & Green, 1999).

Table 7.1

Region of Birth of Immigrants by Period of Immigration, Canada

Region of Birth	% by Period of Immigration	
	Before 1971	2006–2011
United States	5.0	3.9
Caribbean, Central, and South America	5.4	12.3
Africa	1.9	12.5
Europe	78.3	13.7
Asia and Middle East	8.5	56.9
Oceania and Other	0.8	0.6



Data Source: StatCan (2013d)

Based on NHS and census data, this table shows the changing regions from which immigrants to Canada originated. Patterns have shifted significantly since the 1970s, when the majority of immigrants were European. Today, most immigrants were born in Asian countries, specifically the Philippines (13.1%), China (10.5%), and India (10.4%) as of 2006–2011 (StatCan, 2013d).

Today, 20.6% of Canada's population is foreign-born, the highest proportion in any G8 country (StatCan, 2013d) (see also Table 7.1). Immigration in Canada is still classified according to three main categories: economic immigrants, family class, and refugees, with 62% of all immigrants in 2012 in the economic stream. The goal is to raise this share to 70% in the years ahead (CIC, 2014b).

Most of the programs that enable permanent immigration to Canada also have an economic focus, including Express Entry (including the Federal Skilled Worker Program (FSWP), Federal Skilled Trades Program, and Canadian Experience Class), the Quebec-selected skilled workers program, the Start-Up Visa Program, the Self-Employed Persons Program, the Provincial Nominee Program, the Caregiver Program, and the Immigrant Investor Venture Capital Pilot Program. The remaining programs are targeted at family unification (through family sponsorship) and humanitarian objectives (refugee and asylum services) (CIC, 2015b).

Selection in the FSWP is largely based on the human capital model, which takes a broader, longer-term perspective on desirable human capital characteristics (e.g., education, experience) (see Box 7.1). This is in contrast to the goals of other selection models with closer ties to the labour market, such as meeting occupational skill shortages (e.g., Canadian Experience Class, Provincial Nominee Program). The Panel noted that closer ties to the labour market may potentially have negative impacts on innovation, through favouring the current occupational structure over general assets (which may be advantageous in an environment where innovation is triggering changes).

Box 7.1
The Federal Skilled Worker Program and the Points System

The FSWP is one of the primary access points to permanent immigration to Canada (CIC, 2014a). Based on an evolving points system that was introduced in 1967 (Green & Green, 1999), applicants are assessed according to observable characteristics that are used to predict labour market success. These include official language skills (28 points), education (25 points), experience (15 points), age (12 points), arranged employment in Canada (10 points), and adaptability (10 points) (CIC, 2015a). Scores are ranked, out of a total of 100 points. Eligible for consideration are 24 occupations (with an overall cap of 5,000 new applications), predominantly in engineering and medical technology. Applicants must possess a minimum of one year's experience in any of these occupations, have an offer of employment, or be eligible to apply through the PhD stream (CIC, 2014a).

In contrast to permanent immigration, temporary labour migration is another form of mobility. Both permanent and temporary immigration strategies are important enablers of access to the international market of STEM-skilled workers, but they fulfil different roles. Temporary immigration authorizes foreigners to work for a specified period of time in a particular occupation, generally for a particular employer. Created in 1973 to address short-term labour requirements for seasonal agricultural workers, live-in caregivers, and skilled workers, the Temporary Foreign Worker Program (TFWP), jointly administered by Citizenship and Immigration Canada and ESDC, has evolved to include several types of workers (Foster, 2012; Gross, 2014). The formerly nimble TFWP increased from 49,000 to 84,000 participants within a decade, mostly due to greater admittances of low-skilled labour (ESDC, 2014a). Occupations with high proportions of temporary foreign workers tend to be concentrated at opposite extremes of the job spectrum. While concerns about low-skilled foreign workers dominated media headlines in 2014, the Panel's focus is on the workers at the other end of the spectrum: an internationally mobile pool of highly skilled, advanced, and specialized STEM labour (see Foster, 2012).

The TFWP has enabled a relatively high amount of international mobility, and occupationally targeted immigration policies can help ensure alignment between Canadian economic needs and foreigners' skill sets. However, the TFWP presents limited opportunities for participants to permanently immigrate to Canada. The Panel also highlighted several important program trade-offs. For example, attracting highly skilled STEM workers to fulfil immediate and short-term occupational requirements can cause skilled Canadian workers' wages to be suppressed. The Panel suggested that this process may also undercut the incentives for (i) firms to train the necessary Canadian workers or promote recent graduates to more responsible roles (e.g., engineers — recall Box 6.1); (ii) individuals to invest in their own skills; and (iii) foreign workers to invest in their communities.

Given these considerations, the Panel cautioned that it is important to ensure that skilled workers are admitted to meet short-term, firm-specific needs in response to a temporary increase in demand that is unlikely to be sustained. An alternative approach is to make available long-term, sustainable options that support permanent immigration, rather than allowing firms to have continuous access to skills without committing to training, and creating a pool of guest workers with limited rights.

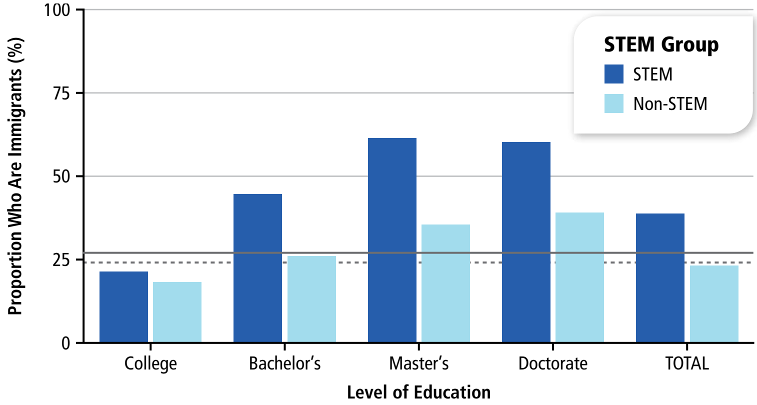
Due to several concerns, major reforms in 2014 recast the TFWP as a last resort for employers to fill jobs for which qualified Canadians are not available, and the new International Mobility Programs aim to "advance Canada's broad economic and cultural national interest," instead of filling specific jobs (ESDC, 2014a). Concurrently, the developing Expression of Interest system, billed as an "active recruitment" model, is intended to be responsive to immediate labour market needs (CIC, 2014b). Outcomes of such program changes remain to be observed.

7.1.1 STEM-Skilled Immigrants in Canada

Immigrants make up the majority of STEM degree-holders at the post-graduate level, and are under-represented among those with college credentials. At 23.7% of Canadian adults, immigrants are a highly educated cohort (see Appendix B). They represent 26.1% of all people with a post-secondary credential, translating to 17.5% of all people with a trades certificate, 23.2% of those with a certificate or diploma below the bachelor level, and 33.8% of those with a bachelor's degree or above. Immigrants make up 49.7% of all STEM degree-holders (at the bachelor level and above). Among individuals aged 25-54, immigrants represent 61.4% STEM master's degree-holders, and 60.2% of STEM doctoral degree-holders (Figure 7.1) (see also Appendix B). By comparison, immigrants hold 28.8% of all non-STEM degrees (Appendix B).

Of university-educated immigrant men aged 24 to 34, 46% have a STEM degree compared with 32% of Canadian-born men in the same age range. A similar pattern holds for young immigrant women, who are twice as likely as Canadian-born women to possess a STEM degree (23% versus 13%) (Hango, 2013:9).

In general, immigration is a major source of STEM skills (people with STEM degrees) and STEM degree-holders in Canada. In addition to targeted immigration policies, cultural values, attitudes, and preferences have been shown to play a role in the level of interest that individuals and groups tend to have in STEM futures (Sjoberg & Schreiner, 2005).



Data Source: StatCan (2013i, 2014n) and Panel calculations

Figure 7.1

Immigrants as a Proportion of STEM Graduates in Canada, by Gender and Education Level, Aged 25 to 54, 2011

The data used in this figure include all individuals with a post-secondary degree (college certificate, bachelor's degree, master's degree, or doctorate), aged 25 to 54 in 2011. The dotted horizontal line indicates the proportion of the population (aged 25 to 54) who are immigrants, while the solid grey line indicates the proportion of those with a post-secondary credential (among those shown) who are immigrants. Bars below the solid line indicate groups where immigrants are relatively under-represented (e.g., among college graduates), while bars above the line indicate groups where immigrants are relatively overrepresented (e.g., among STEM degree-holders above the bachelor's level).

Immigrants and Innovation, Productivity, and Economic Outcomes

As described in detail in Chapter 2, a few studies have found that STEM-skilled immigrants exert a positive influence on innovation and productivity. Despite having poorer labour market outcomes than non-immigrants, as well as representing a relatively small share of the population, U.S. research indicates that STEM-skilled immigrants have a disproportionate impact on innovation, as defined by their patenting advantage (Hunt & Gauthier-Loiselle, 2010; Kerr & Lincoln, 2010; Moser *et al.*, 2014). Results from the only major Canadian study on the effects of STEM on productivity suggest that foreign STEM workers generate significant spillover benefits for Canadian-born workers (Peri & Shih, 2013). Peri and Shih (2013) found that a 1 percentage point increase in the share of immigrant STEM workers increased the wages of non-STEM university-educated Canadian workers in the region by 2.8 to 6.4 percentage points. These large estimates are accompanied by large standard errors, meaning that there appears to be a positive effect, but the exact size is difficult to establish. It is also difficult to determine whether increasing the number of domestic STEM workers would have a similar impact.

More research to clarify these findings could have potential implications for prioritization of the educational backgrounds of prospective migrants in the Canadian immigration system. The Panel also recognized that the new perspectives, cultural knowledge, and social capital introduced by diaspora networks more broadly represent valuable gains from which Canada can profit (Bitran & Tan, 2013).

The reciprocal economic benefits of STEM skills for immigrants themselves represent the other half of the equation. Based on the points system, potential newcomers are evaluated on their education, work experience, and job offers as a proxy for skills. It follows that immigrants' earnings could serve as an indication of the value of these skills, which could be expected to be reasonably high compared with the existing workforce. This is not the case. Despite relatively high levels of education, immigrants (especially those who have been in Canada for less than five years) tend to have higher unemployment rates and lower employment rates than individuals born in Canada (Drummond & Fong, 2010). Further, while a comparatively higher proportion of immigrants hold post-secondary degrees, there is a large disparity between the earnings of immigrants and Canadian-born workers. The earnings gap between immigrants and non-immigrants is even larger for those with a university degree (Drummond & Fong, 2010). Previous generations tended to be able to close this gap, but census data dating back to 1975 indicate that the earnings gap has since widened and become more difficult to close over time (Drummond & Fong, 2010). For STEM degree-holders specifically, about 72% of immigrants, compared with 77% of non-immigrants, were employed in 2011, and 7% and 5% (respectively) were unemployed (StatCan, 2013i).

The issue of immigrants' relatively lower labour market outcomes is troublesome and complex. A clearer understanding of these outcomes requires detailed analysis that includes several variables, including country of origin, location of education, language and literacy skills, experience, credential recognition, and the impact of business cycles on time of arrival. If any or all of these criteria are insufficiently fulfilled, skilled immigrants may be driven to take lower-paying positions unrelated to their educational and occupational backgrounds (Drummond & Fong, 2010). Among other explanations, immigrants' low earnings are often linked to the specificity of human capital in their home country. Skills gained in a home country cannot necessarily be directly transferred to a host country. Using survey data, Bonikowska *et al.* (2008) and Ferrer *et al.* (2006) find that immigrant literacy skills (French- or English-language skills) are lower than those of Canadian-born workers, and that these skills have a significant effect on immigrants' earnings. Language ability is an input in the production of skills that are usable in the Canadian market. Neither study found evidence that immigrants receive lower returns to the types of cognitive skills measured compared to otherwise equivalent Canadian-born workers. Rather, if skill levels were equal, the earnings differential would be expected to narrow or disappear. In this context, lower levels of usable skills (rather than discrimination, in the sense of equally productive workers being paid unequally) explain some important differences in earnings (Ferrer *et al.*, 2006; Bonikowska *et al.*, 2008).

Location of education is another major factor. Immigrants with a foreign education have lower earnings than immigrants with a Canadian education (Picot & Sweetman, 2005; Bonikowska *et al.*, 2008) (see Appendix B for data on the proportion of people in Canada with a foreign education). More specifically, a comparison of immigrants' Canadian labour market earnings with source-country mathematics and science scores revealed that source-country educational quality is one factor in explaining differences in immigrants' and non-immigrants' returns on education in the Canadian labour market (Sweetman, 2004). Based on combined census files from the 1980s and 1990s, Sweetman found that immigrants from source countries with the highest international mathematics and science test scores (e.g., Singapore, Hong Kong) tend to experience higher returns on education than those from countries with the lowest test scores.

Age of arrival is also a consideration: those who were under 10 years of age when they immigrated to Canada experienced similar labour market outcomes to those who were Canadian-born. Since the majority of young immigrants would experience the Canadian education system, age of arrival generally functions as a proxy for location of education (Sweetman, 2004). Immigrants' declining economic outcomes have been well studied (see Picot & Sweetman, 2005 for a review), but the Panel agreed that continued investigation into this important issue would be valuable.

7.1.2 International Migration: Moving Forward

While STEM-skilled immigrants are a critical source of human capital, a synthesis of the research suggests that skilled immigrants are not currently meeting labour market needs to the greatest possible extent. This is largely due to difficulties with appropriately connecting immigrants with the Canadian labour market: the skills of Canada's highly skilled immigrants are often underutilized (McDaniel *et al.*, 2014). To this end, researchers suggest a re-visitation of the points system, broadening of immigration policy, and the improvement of foreign credential recognition (see a review from McDaniel *et al.*, 2014).

Researchers also note that caution should be exercised in relying on employer expectations to predict labour market conditions. Employers may benefit from increased immigration levels, yet remain protected from the consequences of an oversupply of specialized skill sets (e.g., the influx of foreign ICT workers during the late 1990s and early 2000s, and the subsequent dotcom labour bust) (Skuterud, 2013). For policy-makers, Labour Force Survey-reported wage and unemployment rates represent an alternative to surveys of employer needs. Data limitations (i.e., the survey does not specify the immigration program through which foreign-born Canadians entered the country) could be overcome by linking Survey data with the administrative Longitudinal Immigration Database, which provides details on immigrants' landing records (see Table 8.1 for more on the importance of comprehensive labour market data).

Others point to the importance of prioritizing immigrants' education, language skills, and networks, instead of an overly heavy emphasis on occupation (Drummond & Fong, 2010). As illustrated by the dotcom bust, labour requirements in certain industries can swiftly transfer to other industries more quickly than the immigration system can respond, resulting in suboptimal outcomes for skilled immigrants as well as the Canadian economy more broadly (Drummond & Fong, 2010). Thus, the balance between evaluating the general characteristics of immigrants (based on the points system) and specific occupational backgrounds (to respond to occupational requirements) is in need of further analysis. In either case, language programs, experience and credential recognition, and employer-sponsored initiatives have been recognized as critical to empowering new Canadians to reach their potential (Drummond & Fong, 2010).

7.2 THE GLOBAL MARKET FOR STEM SKILLS

While immigration is a key contributor to Canada's supply of STEM skills, STEM skills are global skills that can be transferred through both immigration *and* emigration. In contrast to concerns in the 1990s about *brain drain,* the loss of skilled and educated Canadians due to emigration appears to be more than offset by the immigration of skilled labour from around the world (Dumont & Lemaitre, 2005; DeVoretz, 2006). From 2008 to 2010, Canada's net migration rate was 7.6 per 1,000 persons, meaning that more people entered Canada than left. This was higher than the OECD average (3.2), the United States (2.4), and New Zealand (2.7), but lower than Australia (13.3) (OECD, 2013e). Emigration statistics are difficult to track because departures are not documented as closely as arrivals (Eurostat, 2010), and Canadian data are extremely limited. Existing data suggest that like immigrants to Canada, Canadian expatriates living in OECD countries represent a highly educated cohort, with about 40% holding a post-secondary degree (Dumont & Lemaitre, 2005). Overall, Canada does not appear to be losing skilled individuals.

Within the OECD area, Canada is one of eight countries that are net beneficiaries of highly skilled migration from other OECD countries (Dumont & Lemaitre, 2005). Of Canadian émigrés, a strong majority move to the United States (Dumont & Lemaitre, 2005), although this number is relatively small (2.2 per 1,000 in 2006) (Dion & Vezina, 2014). These Canadian-born émigrés appear to be young, educated, employed, and working in highly specialized fields, including the professional, scientific, and technical services sector (Dion & Vezina, 2014).

7.2.1 Brain Circulation

In the late 1990s and early 2000s, outflows of highly skilled and educated Canadians, primarily to the United States, were extensively documented in the "brain drain" literature (see Mishagina, 2012). Attention to the issue has subsequently diminished, with recent findings suggesting that about only about 1 to 2% of recent Canadian graduates live in the United States (1995, 2000, and 2005 cohorts) (Boudarbat & Connolly, 2013). Canadians with doctorates and graduates from STEM[45] programs are the most likely cohorts to move but evidence indicates that many return to Canada. Nearly 50% of graduates from the 2000 cohort moved, but by 2005 about half had returned and a majority of those remaining intended to return.

Although small in number, returning graduates bring with them international experience and skills valued by domestic employers, as shown by, upon their return, higher earnings (up to 18% more on average) than graduates who stayed in Canada. Provided that these graduates return, this mobility, which is more of a *brain circulation* than a drain, may ultimately be of benefit to Canada (Boudarbat & Connolly, 2013). Other research shows that stay rates are much higher for Canadian science and engineering students who earn their doctorate in the United States. Of the 326 who did so in 2006, 59% remained in the United States in 2007 and 55% remained as of 2011. Stay rates of these students declined from 65 to 55% from 2001 to 2011 (Finn, 2014).

Brain circulation, a series of movements by highly skilled workers across states, is used to describe the process of how immigrants become émigrés (DeVoretz & Ma, 2002). Movement may be varying degrees of "temporary," varying from long enough to send remittances home to acquiring citizenship and accumulating human capital before moving again (DeVoretz, 2006). In Canada, multilateral brain circulation has been attributed to several causes: a strong North American economy and an expanding information technology sector increased demand for highly skilled immigrants during the 1990s, dual citizenship policies facilitated continuous movement, temporary visas proliferated (including H1-B visas in the United States), and China eased exit requirements to allow highly skilled citizens to leave for educational purposes (DeVoretz, 2006). Few Canadian studies have explored the outward mobility of foreign-born skilled workers (Mishagina, 2012), although research suggests the emergence of a China-Canada-Hong Kong circulation of the young and highly educated (DeVoretz, 2006).

While access to subsidized education and the prospect of a Canadian passport may initially attract immigrants, these factors can also push skilled immigrants to return home or on to a third country, with the goal of maximizing the rate of return on acquired human capital. However, unlike the case of brain drain, where one country experiences a loss of human capital and the other gains, emerging economies are drawing some skilled immigrants home, bringing with

45 In this case, STEM is limited to mathematics, computer and information sciences, and architecture, engineering, and related technologies. For 2000 and 2005 cohorts, having a degree in physical and life sciences and technologies also increased an individual's likelihood of living in the United States.

them skills, technology transfers, and links to foreign networks (Saxenian, 2005). Immigrants who do not permanently return may send remittances to family in their country of origin, and use their linguistic and cultural skills and contacts to develop international business relationships. Such networks can accelerate the globalization of labour markets and open new opportunities for trade, investment, and entrepreneurship (see Box 7.2). In Silicon Valley, for example, Indian engineers have become valuable agents linking local firms with low-cost software expertise in India (Saxenian, 2002). New transportation and communications technologies enable the smallest of firms to build partnerships with foreign firms to access global expertise, markets, and cost-saving production strategies (see Saxenian, 2002).

Box 7.2
Entrepreneurs: A Snapshot from Ontario

Since 2005, the MaRS Discovery District has helped entrepreneurs develop Ontario-based startup ventures in the health, cleantech, and ICT sectors. With a goal of fostering economic and social prosperity, this independent charity aims to help startups grow. Available data precluded the Panel from drawing a link between the educational backgrounds of entrepreneurs and their current contributions to innovation; however, a 2013 survey provides some insight into the demographics of entrepreneurs in STEM-related startups.

Of the 1,027 MaRS startup clients surveyed, 27% were in health, 14% in cleantech, and 59% in ICT. Out of more than 700 respondents, the majority (85%) of founders were men, over the age of 30 (67%), and working on their first startup (55%). About one-third of all employees were under the age of 30. Linking to the Panel's findings about immigrants and innovation, 42% of founders were born outside of Canada, and 39% of ventures had at least one founder born outside of Canada. Women held 19% of all 1,224 executive leadership positions and 19% of ventures had at least one woman founder.

In 2013, health-related startups raised the most capital ($172 million of the $451 million total), but the largest revenues were earned by ICT firms ($93 million of the $210 million total). A total of 199 patents were issued in 2013.

(MaRS, 2013)

Contrary to concerns about foreign workers displacing Canadians, evidence described in Chapter 2 suggests that STEM-skilled immigrants bring with them a unique set of positive externalities or unexpected benefits. In addition to exerting a disproportionate impact on innovation, these individuals generate significant spillover benefits for local workers in the form of increased wages. New research from Docquier *et al.* (2013) reveals that between 1990 and 2000, particularly large and significant positive long-run wage effects were associated with immigrants in Canada, for both average and non-college educated workers (0 to 3% and 3 to 5%, respectively).[46] Suggesting a reason behind such positive effects, Docquier *et al.* note that Canada's immigration policy favours educated immigrants (like Australia and New Zealand, which experienced similar effects). The negative wage effects of Canadian emigration were very small (less than -1%); Canada has one of the lowest rates of emigration in the OECD (Docquier *et al.*, 2013). These examples reiterate a central implication of brain circulation: it can enable prosperity for immigrants, sending countries, and receiving countries.

7.2.2 International Students and Researchers: On the Move to Acquire STEM Skills

Skilled international students represent a growing and important population in the context of the global market for STEM skills. As is the case with skilled labour, a flow of students moves to and from Canada. With a growth rate of about 8% per year since 2007, the number of international students overall in Canada is growing at a faster rate than in any other country (DFATD, 2014). Canada's International Education Strategy aims to almost double the number of international students in Canada from about 240,000 in 2011 to 450,000 by 2022 (DFATD, 2014).

Together, the United States (16.5%), United Kingdom (13.0%), Germany (6.3%), France (6.2%), Australia (6.1%), and Canada (4.7%) had received more than half of all foreign students globally as of 2010–2011 (OECD, 2013f). However, in the same years, international enrolments in Canada (7.4% of all post-secondary students) were relatively similar to the OECD average (6.9%), but well below enrolments in other popular English-language destination countries such as Australia (19.8%), the United Kingdom (16.8%), and New Zealand (15.6%) (OECD, 2013f). Coming primarily from China (26.9%), the United States (7.7%), France (7.4%), India (6.0%), and South Korea (4.4%), about 5% of all internationally mobile students were enrolled in Canada in 2010 (CBIE, 2012; StatCan, 2014e).

46 Depending on whether an optimistic, intermediate, or pessimistic scenario was calculated.

Although Canada has positive net migration overall, the share of post-secondary international students in Canada (7.4%) (OECD, 2013f) is much greater than that of Canadian students who study abroad (2.2%) (AUCC, 2007).[47] This is also small compared with the share of European, Australian, and U.S. students who choose to study abroad (DFAIT, 2012). Each of these regions has implemented major programs to facilitate international learning among domestic student populations (Simon, 2014). According to Canadian university and college administrators, top reasons for promoting study abroad include developing global citizens (77%), strengthening international understanding (56%), developing cross-cultural skills (54%), and increasing job skills and employability (38%) (AUCC, 2007).

Finally, international researchers (faculty members with working visas) at post-secondary institutions are a related cohort, accounting for 6% of faculty members in Canada in 2008 (an increase of 21% from 2004). From 1997 to 2010, Canada experienced a positive migration flow (0.9%) of researchers into Canada. In net immigration, the fields of research with the highest inflow of researchers were ICT, engineering, chemistry, and clinical medicine, although the numbers overall were low (CCA, 2012a). Bibliometric data suggest that Canadian scientists have some of the highest mobility rates in the OECD: 13.3% of Canadian scientific authors[48] have a previous affiliation abroad (OECD, 2013c). Canada and the United States also demonstrate among the highest number of bilateral scientific flows in the OECD, with a total exchange of nearly 20,000 scientists from 1996 to 2011. Bilaterally, Canada experiences a net outflow of scientific authors to the United States, but overall, it has maintained a net positive inflow of scientists (OECD, 2013c).

7.2.3 International STEM Students: Trends for 2000 to 2011

The proportion of international students in Canada increased at all levels of study (except the doctoral level), across all fields, from 2000 to 2011 (Panel calculations based on StatCan, 2014c). The share of international students graduating from doctoral STEM programs has been fairly constant since 2000, generally between about 12 and 20% (depending on the program). Across all fields of study, the proportion of international student graduates increased more quickly at the master's level than at all other levels of education, from around 7% in 2000 to 16% in 2011.

47 OECD data are from 2010. Association of Universities and Colleges of Canada data are based on 2006 results.

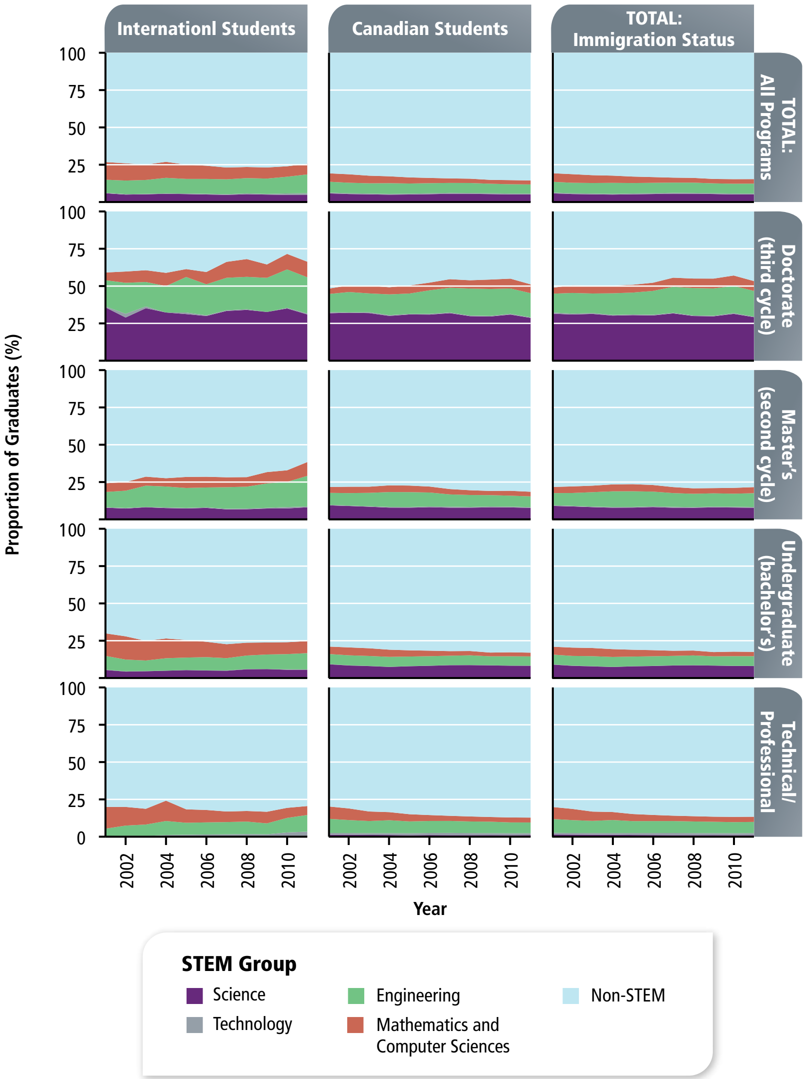
48 *Scientific authors* as listed in the Scopus database, with at least two peer-reviewed publications over the reference period. Note that bibliometric indicators are experimental and capture a partial image of international mobility.

In recent years, the highest shares of international student graduates have been in master's programs, particularly in STEM fields. In 2011, around 35% of master's graduates in engineering, and mathematics and computer sciences were international students.

In the same period, the proportion of international students graduating from STEM programs was higher than from non-STEM programs. There are no signs of a reversal in this trend. Out of all fields, mathematics and computer sciences consistently had the highest proportion of international student graduates at all academic levels, over most of the period (Panel calculations based on StatCan, 2014c).

International students are more likely than Canadian students to graduate from a STEM field (Figure 7.2). This is true at all levels of study, although non-STEM programs remain more popular overall. The proportion (25%) of all international students who graduate from STEM programs has remained consistent since 2000. This is in contrast to the slow decrease in the proportion of Canadian STEM graduates compared with non-STEM graduates (see Chapter 6). The decline has been driven by a shrinking proportion of graduates from mathematics and computer sciences programs, and an increasing proportion of graduates from non-STEM programs.

Across all levels of study a higher proportion of international students than Canadian students graduated from engineering, and mathematics and computer sciences programs from 2000 to 2011. The proportion of science graduates among Canadian and international students is relatively similar, with few changes over time. Although the overall share of international PhD graduates remained relatively stable from 2000 to 2011 (around 15 to 18%) (not depicted in Figure 7.2), the majority of international doctoral students (over 60%), like a slight majority of Canadian doctoral students (around 50%), graduate from STEM programs (Panel calculations using StatCan, 2014c).



Data Source: StatCan (2014c) and Panel calculations

Figure 7.2

Fields of Choice in Canada among International and Canadian Students, 2000–2011

This figure shows the proportion of international and Canadian (including permanent residents) students who graduated from 2000 to 2011 from Canadian institutions in STEM and non-STEM fields.

7.2.4 Retaining a STEM-Skilled and Culturally Skilled Population

International students may eventually become Canadian citizens, or "unofficial ambassadors" upon their return home (StatCan, 2014e). Attracting and retaining international students is an example of how domestic education and immigration can be complementary assets in developing a knowledgeable and flexible workforce. Coordinated, collaborative action on behalf of the relevant federal and provincial actors is a key component in achieving this goal. While international student migration has social and cultural benefits beyond enhancing host country skills capacity, students are generally regarded as potential skilled workers with the capacity to integrate into the Canadian labour market due to their known credentials, skills, experience, and social networks (Chaloff & Lemaitre, 2009; She & Wotherspoon, 2013). The Panel noted that retention of skilled immigrants is a precondition for positive effects on innovation and productivity to occur. However, despite comparatively broad and easy access to entry and settlement opportunities,[49] the average share of foreign students transitioning to Canadian permanent resident status was 5.4% from 1999 to 2009 (van Huystee, 2011).[50] Expressed in numbers, in 2012, 7,797 foreign students in Canada transitioned to permanent residency, out of the 265,404 who were present (CIC, 2012). (Note, however, that a large proportion of these students would be in the process of completing their studies, and thus not ready to transition.)

In comparison, the Australian government started actively recruiting former international students as migrants in 1998 (Ziguras, 2012). By 2002, international students were responsible for half of all skilled migration applications (Shaw, 2014). McHale (2010) highlights the potential benefits of following Australia's example of increasing the number of points awarded to prospective immigrants with Canadian post-secondary education. Research suggests that there are options to facilitate the integration of international students into the Canadian labour market. Employers can increase their awareness of immigration laws pertaining to international students, and governments can identify common obstacles faced by international students and increase access to immigrant settlement and integration services, language programs and bridge programs (Desai Trilokekar *et al.*, 2014). Of note in this context is the Canadian Experience Class program. Introduced in 2008, this sizeable program allows some skilled temporary foreign workers and international students with a Canadian degree and at least one year of work experience to apply for permanent residency without leaving the country. Post-secondary institutions

49 For example, post-graduation work permits enable students to work for a maximum of three years after graduating (CIC, 2013).

50 This is a conservative estimate, based on the assumption that most students transition directly from their studies and foreign student status to permanent resident status.

and employers play a significant role in the selection process, increasing the likelihood that immigrants' foreign work experience and educational credentials will be recognized. Evidence on the impacts of this program is encouraging, but limited (Ferrer *et al.*, 2014).

More recent changes to the *Citizenship Act* that affect some international students have attracted criticism. Previously, every day individuals spent in Canada as a non-permanent resident (including international students and foreign workers), counted as a half-day of residence towards their citizenship application, up to a maximum of two years. As of 2014, this pre-permanent residency time is no longer counted, and residency requirements have simultaneously been increased from three out of four years to four out of six years. Some observers have raised concerns that such changes may make it more difficult for international students, who have already been living and presumably integrating into Canada, to secure legal status (CP, 2014; Griffith, 2014).

7.3 CONCLUSION

Evidence from Chapters 5, 6, and 7 suggests that developing a flexible labour market requires collective, coordinated action to facilitate education, training, and mobility. Mobility is important because STEM skills are global skills that can be transferred through both immigration and emigration. Bidirectional flows of skilled labour increase international connections, and data indicate that the emigration of STEM-skilled Canadians is more than offset by STEM-skilled immigrants. Though they account for a smaller share of the population than Canadian-born individuals, immigrants represent 50% of all STEM degree-holders in Canada. A unique positive externality, or spillover effect, is linked with STEM-skilled immigrants. In addition to exerting a disproportionate impact on innovation, these individuals generate significant spillover benefits for local workers in the form of increased wages. However, due to a number of factors, immigrants can experience difficulties connecting with the Canadian labour market. This is evident in their higher unemployment rates and lower employment rates than Canadian-born STEM degree-holders.

Canada's immigration policy is closely tied to labour market needs. Canada can draw on the global pool for highly advanced and specialized technical experts when the domestic capacity for niche STEM skills does not meet demand. Drawing on temporary international labour to meet demand for skills in broad occupational categories was noted by Panel members as a less sustainable and generally less optimal policy response. The Panel cautioned that it may diminish the incentive for firms to train workers and compensate them accordingly, and it may dissuade workers from investing in their own skills. Referencing the influx of ICT-skilled immigrants in the late 1990s, and the subsequent dotcom bust of the late early 2000s, the Panel raised concern about some potentially negative outcomes of occupationally targeted immigration policies. The Panel believes that there are some instances where targeted programs are valuable for specific short-term needs. However, considering the dynamism of labour markets, the Panel agreed that long-term programs and policies that focus on fundamental skills fulfil an important role in ensuring that Canadians are equipped with the tools needed to navigate an uncertain future.

In addition to other immigration channels, international students represent a largely untapped supply of this type of human capital. Combined with the new perspectives, cultural knowledge, and social capital introduced by immigrant diasporas in general, the long-term benefits of immigration in the form of positive externalities are more critical than the short-term aspect of providing access to temporary labour.

8

Conclusions

- What role do STEM skills play in supporting and fostering innovation, productivity, and growth?
- What is the extent and nature of the global market for STEM skills and how does it interact with the Canadian market?
- How is labour market demand for STEM skills likely to evolve in the future? Which STEM skills are likely to be most in demand?
- What is known about the relative importance of different factors affecting Canada's supply of STEM skills, especially through the Canadian learning system and international migration?
- Moving Forward: Improving Data and Research
- Final Reflections

8 Conclusions

Skills make, and will continue to make, critical contributions to Canada's prosperity. However, there is uncertainty about precisely which skills are needed to thrive in tomorrow's knowledge-based economy, how skills directly contribute to innovation and productivity, and if some skills are more connected to these goals than others. Because STEM skills have become increasingly central to many areas of economic activity, many observers are particularly concerned with the extent to which Canadians are equipped with these skills. The answers to these questions are relevant to individuals, firms, educators, and policy-makers. They hold implications for labour market supply and demand, innovation, and productivity.

Within this context, the Panel responded to the following charge:

> *How well is Canada prepared to meet future skill requirements in science, technology, engineering and mathematics (STEM)?*

Based on its review of the best available evidence, the Panel found that at the national level, there is no evidence of a current imbalance in STEM skills. In general, the labour market is functioning well in the short term, with individuals choosing fields of study and occupations based on market signals and personal preferences. Smaller-scale mismatches by region and industry may exist, but they are difficult to assess with available information. For example, data from about 2006 onwards show that Alberta and Saskatchewan generally have excess demand for labour in all occupations, including STEM-intensive occupations, while moderate conditions of excess supply exist in parts of in central and Atlantic Canada.

Long-term labour market demands, however, are difficult to predict. It is especially challenging to estimate future demand for advanced STEM skills: a range of external forces influence the economy, including constant changes in technology that can profoundly alter the nature of work. Most projections are inherently unreliable because they are based on the assumption that historical relationships will continue in the future.

It is not possible to definitively determine the skills and knowledge that will be required for the jobs of the future. However, the Panel agreed that proactive, long-term strategies are important to keep a range of economic options open and equip individuals with skills to help them respond to changing employment demands:

Ongoing investments in fundamental skills for STEM literacy: There are many types of fundamental skills, and STEM education provides a rich environment for developing some of them, such as mathematics, computational facility, reasoning, and problem solving. Fundamental skills for STEM are prerequisites for a wide variety of future education and career options, and are thus important for all Canadians — beginning at an early age. They are the building blocks of more complex STEM skills, from pre-primary education through to post-secondary. Importantly, evidence suggests that mathematics learning is also linked to student success in other areas of study, including reading. Results from standardized tests demonstrate that Canadian youth perform relatively well in science and mathematics-related domains, but there are many opportunities for improvement.

Maintaining Canada's capacity for producing advanced STEM skills: Dedicated assets remain important for basic research. Continuing Canada's tradition of research excellence and high-quality post-secondary education is critical, as is increasing the participation of women and Aboriginal peoples in STEM. Flexibility in education and training systems is required to provide workers with options for continuous learning. Employer-sponsored training, for new employees and for ongoing professional development, is a vital component of this goal.

Providing opportunities to develop complementary skills: Complementary skills, including communication, teamwork, and leadership are demanded by employers and have been identified as important to innovation. Improvements and expansions in work-integrated learning can bridge the divide between education and work, thereby enabling the development of these assets.

Building a strong immigration system: Immigrants are a major source of STEM skills for Canada, representing about 50% of all STEM degree-holders. Evidence also suggests that STEM-skilled immigrants exert positive impacts on innovation and productivity. However, highly skilled immigrants are often underutilized in the Canadian labour market.

While Canada is performing well in many ways, the Panel concluded that there exists significant room for improvement in all of these areas to enable Canada to be strategically positioned to face future labour market uncertainties. Collective, coordinated action on behalf of post-secondary institutions, government, industry, community organizations, and the immigration system is important to facilitate education, training, and mobility.

8.1 WHAT ROLE DO STEM SKILLS PLAY IN SUPPORTING AND FOSTERING INNOVATION, PRODUCTIVITY, AND GROWTH?

Core tenets of standard theories of economic growth include the acquisition of human capital and technological progress for improvements in productivity and living standards. As a facet of human capital that plays a critical role in developing and adopting new technologies — which enable workers to do more in less time, or with fewer resources — evidence suggests that STEM skills contribute to innovation, productivity, and economic growth. However, considerable uncertainty remains about the specific contribution of STEM skills and the magnitude of their impacts. Further, increasing the quality or quantity of workers with STEM skills will neither automatically translate into increased innovation in the Canadian economy, nor reverse Canada's poor productivity record. To generate growth and increased living standards, the business sector must also demonstrate demand for these skills. Demand-side issues cannot be solved with supply-side solutions.

STEM and Innovation

The theoretical reasons for a link between STEM skills and innovation are clear (recall Figure 2.1). A considerable body of empirical research supports the idea that higher cognitive skills and human capital development promote technological progress: highly STEM-skilled researchers may develop new products, services, and processes. STEM-skilled workers can identify more efficient ways of doing their jobs and apply these innovations to increase their own productivity and that of others. However, there is limited evidence on the exact role played by STEM skills. The analysis required to isolate the specific contribution of STEM skills from the contribution of other skills and factors is very difficult and relevant data are often unavailable. Importantly, while STEM skills play a fundamental role, they interact with important complementary skills such as communication, teamwork, leadership, and risk-taking to generate innovations. Not all innovations are STEM-based.

The only clear evidence of the impact of STEM on innovation comes from a few recent studies that investigate the effect of STEM-skilled immigrants on innovation. Generally, these studies suggest that STEM-skilled immigrants increase innovation, in the form of increases in patenting (a limited indicator). This is not the case in all markets, and evidence suggests that non-STEM skills also play a role, but more research is required to clarify these relationships. *In the Panel's view, the balance of evidence on the impact of STEM skills on innovation suggests that they generate significant benefits.*

STEM and Productivity

Economic theory and evidence suggest that innovation raises productivity: technological progress is recognized as an important source of economic growth, for example. However, the particular mechanism through which technological progress occurs still remains largely unknown. Thus, there is currently little evidence that directly links STEM skills to productivity growth, although innovation is the primary channel through which STEM skills are understood to boost productivity. STEM skills foster innovative activity in several ways, and this innovative activity is a driving force behind growth in productivity and output.

In addition to the unique role that STEM skills play in technological progress, many of the skills, knowledge, and abilities relevant for STEM can also boost the productivity of workers engaged in activities other than R&D. While several factors affect wages, including productivity, one of the most commonly cited pieces of evidence of the high productivity of STEM skills is the wage premium commanded by STEM occupations and STEM credentials. At the aggregate level, STEM workers generally earn higher wages than non-STEM workers with the same level of educational attainment. To the extent that wages are indicative of labour productivity, this is evidence that, at the aggregate level, STEM workers are more productive. However, this general pattern obscures considerable variation across a number of variables, such as gender, immigration status, level of education, and even STEM field. For example, graduates in engineering, and mathematics and computer sciences earn relatively high wages, whereas median wages for graduates in science and technology fields are similar to wages earned by those in non-STEM fields.

There is limited research that attempts to directly estimate the effects of STEM on productivity. The only two major studies involve the impact of foreign STEM workers on productivity in Canada and the United States, with results suggesting that foreign STEM workers generate significant spillover benefits for domestic workers. Peri & Shih's (2013) Canadian study found that a 1 percentage point increase in the share of foreign STEM workers employed in a region increased the wages of non-STEM university-educated Canadian workers in the region by 2.8 to 6.4 percentage points. It is estimated that foreign scientists and engineers accounted for significant productivity growth in the Canadian economy. The exact size of this effect is difficult to establish because large standard errors accompany these estimates, and results are preliminary, but the effects appear to be positive. More research may clarify these findings, with potential implications for how the Canadian immigration system may prioritize the educational backgrounds of prospective migrants.

In summary, the best existing evidence of the impact of STEM skills on both innovation and productivity is based upon the positive effects that STEM-skilled immigrants appear to have on domestic outcomes. Taken together, *it is the judgment of the Panel that STEM skills represent a necessary, though not sufficient, condition for innovation, productivity, and growth.* The Panel suggested that in addition to a solid supply of practical and advanced STEM skills (which Canada appears to have), several factors are required to improve Canada's productivity growth. These may include demand for these skills from the Canadian business sector, a STEM-literate population with strong fundamental skills, and the presence of complementary assets to bring ideas to the market.

8.2 WHAT IS THE EXTENT AND NATURE OF THE GLOBAL MARKET FOR STEM SKILLS AND HOW DOES IT INTERACT WITH THE CANADIAN MARKET?

STEM skills are global skills that can be transferred through both immigration and emigration. In contrast to concerns in the 1990s about brain drain, the loss of skilled Canadians due to emigration appears to be more than offset by the immigration of skilled labour from around the world. Today, the flow of skilled immigrants and émigrés across (multiple) states is more often referred to as *brain circulation.* Unlike the case of brain drain, where one country experiences a loss of human capital and the other gains, the international migration of skilled workers can enable prosperity for immigrants, sending countries, and receiving countries. Immigrants who do not permanently return may send remittances to family in their country of origin, and use their linguistic and cultural skills and contacts to develop international business relationships. Such networks can accelerate the globalization of labour markets and open new opportunities for trade, investment, and entrepreneurship.

As demonstrated in Section 8.1, *a unique positive externality, or benefit, appears to be linked with STEM-skilled immigrants.* In addition to positively influencing innovation, new research suggests that these individuals may generate significant spillover benefits for local non-STEM-educated workers in the form of increased wages. Immigrants are a major source of STEM skills for Canada, representing about 50% of all STEM degree-holders. In particular, they are highly represented at the post-graduate level. Combined with the new perspectives, cultural knowledge, and social capital introduced by immigrant diasporas, the Panel concluded that the long-term benefits of immigration are more critical than the short-term aspect of access to temporary labour. More research could clarify these findings (particularly on STEM-skilled immigrants and their connections to innovation and productivity).

Of note is that while Canada clearly benefits from immigration, *highly skilled immigrants are often underutilized in the labour market.* Despite relatively high levels of education, immigrants tend to have higher unemployment rates and lower employment rates than those Canadian-born workers. Location of education, age of arrival, and official language skills emerge as significant factors in this regard. While earlier generations were able to close this gap, data indicate that the disparity has since become more pronounced and difficult to close. This has negative implications for immigrants, the Canadian economy, and the country as a whole.

In terms of Canada's immigration system itself, applicants with close ties to labour market needs tend to be prioritized. The Panel concluded that this may lead to negative outcomes for immigrants in the long run if demand for their once-targeted skill set declines. This policy may also have negative impacts on innovation by favouring the current occupational structure over general assets. Such general assets (e.g., education, networks) may prove advantageous, especially since long-term future demand is difficult to predict. For example, labour requirements in certain sectors can swiftly transfer to other sectors more quickly than the immigration system can respond. The Panel cautioned that an emphasis on temporary migration may undercut the incentive for firms to train and develop employees' skill sets, as well as discourage individuals from investing in their own skills development. In the opinion of the Panel, the unpredictability of labour markets may render short-term responses less useful than long-term, sustainable programs. Short-term responses also limit the potential of productivity effects associated with STEM-skilled immigrants. However, the Panel also suggested that there are instances where targeted programs are valuable for specific short-term needs, such as drawing from the global pool to acquire highly advanced and specialized technical experts when the domestic capacity for niche STEM skills does not meet demand.

Finally, STEM-skilled international students and researchers represent a growing cohort of skilled individuals with the potential to integrate into the Canadian labour market relatively easily due to their known credentials, skills, experience, and social networks. International students are more likely than Canadian students to graduate from a STEM field, at all levels of study. This is particularly true at the doctoral level, where over 60% of international students graduate with a STEM degree (compared with about 50% of Canadian doctoral students). Attracting and retaining international students is an example of how domestic education and immigration can be complementary assets in developing a knowledgeable and flexible workforce. However, the share of foreign students who transition to Canadian permanent resident status is well below 10%. The Panel believes that this represents an opportunity on which Canada can capitalize.

8.3 HOW IS LABOUR MARKET DEMAND FOR STEM SKILLS LIKELY TO EVOLVE IN THE FUTURE? WHICH STEM SKILLS ARE LIKELY TO BE MOST IN DEMAND?

Supply and Demand: STEM Skills in 2015

Based on a review of a number of indicators, including employment and unemployment data, wages, and STEM education and occupation matching, *the Panel did not find any evidence of a current imbalance of STEM skills nationally.* Rather, it concluded that Canada appears to have a well-functioning labour market, where individuals are choosing fields of study and occupations based on factors such as market signals and personal preferences. The Panel acknowledged that a national analysis may not capture regional mismatches. Smaller-scale mismatches by industry and region may exist, but they are difficult to assess with available data.

STEM graduates generally fare better in the labour market than their non-STEM counterparts, with lower unemployment, higher employment rates, and higher wages. However, it is important to note that there exists considerable variation in the above indicators, by gender, level of education, immigration status, and even among STEM fields. Apparent differences between STEM and non-STEM categorizations are in some cases driven by these underlying factors. As a result, the extent to which STEM and non-STEM categories are useful analytically emerged as an important question. For example, differences in labour market outcomes are larger among individual fields of study (e.g., engineering versus science) than between STEM and non-STEM groups on the whole.

In terms of how STEM graduates mobilize their education for employment purposes, the Panel found that most STEM graduates work in occupations that are not STEM-intensive: about 27% of women and 44% of men with STEM credentials end up in STEM-intensive careers. At the same time, STEM graduates are more likely than non-STEM graduates to find jobs that make use of their level of education, regardless of their area of occupation. In other words, STEM degree-holders appear to be relatively less likely to be underemployed.

STEM Skills for the Future?

While long-term trends suggest that demand for high-skilled workers, including those with STEM skills, is increasing, data from about 2000 onwards call the consistency of these trends into question. For example, theories of skill-biased technical change suggest that computerization displaces workers in the "middle skill" category. This category is usually associated with routine tasks that can be easily automated. As these workers are displaced, the wage structure becomes "hollowed out," and the focus shifts to abstract tasks at the upper end of the wage spectrum and manual tasks at the lower end. Such a model of technical change assumes that technology complements high- and low-skill workers. While the theory is strong, it does not completely explain some notable patterns: data from the past 200 years indicate that technological advances have not always increased the demand for skills (though technology can drive the demand for different *types* of skills). Most recently, the 1980s and 1990s witnessed a dramatic increase in demand for cognitive skills, including STEM skills. However, since about 2000, this demand has faded, suggesting that skill-biased technical change can cause a boom and bust in the demand for cognitive tasks. However, non-routine cognitive skills are still expected to command a premium over manual skills, and fundamental skills for STEM remain important for all Canadians.

A forecasting model is a tool used to understand future labour market trends. COPS results project that the national labour market will generally be in balance until 2020, but national projections may conceal imbalances at regional levels. Due to a number of necessary assumptions, the reliability of future projections is limited. Long-term future demand is difficult to predict — especially demand for advanced and specialized skills.

Technological change can change ways of working, but the evidence is unclear about whether or not past trends in the relationship between technology and the labour market will continue to hold in the long run. In addition, projections are limited in their ability to predict future occupational needs, and definitively determining the skills and knowledge required for these jobs is not possible. New technologies are also creating industries, occupations, and career paths that previously did not exist. Under normal market conditions, investing heavily in narrowly specialized training has significant risks for individuals and for society. Changes in demand for niche skills over time may result in obsolete or undervalued skills. Deep investment in one area has a high cost in terms of not developing other skills, in individuals and in society. Although investment is important for basic research, as well as development of new innovations, interventions to increase the number of STEM-skilled workers should not be required in a well-functioning market.

Although it is not possible to identify the specific skills and knowledge required for the jobs of the future, research suggests that investing in an adaptable workforce is a sensible response to growing uncertainty about the future of technology, the changing nature of work, and expected demands for skills. This proactive strategy can be implemented through the development of assets. As noted at the beginning of this chapter, STEM skills are global skills that open up a variety of education and job pathways and opportunities for individuals. Upon reviewing the evidence, the Panel judged that STEM skills represent an important but not sufficient condition for innovation, productivity, and economic growth.

Complementary skills, such as leadership ability, business skills, creativity, and communication skills, may help to amplify the effects of practical and advanced STEM skills. Complementary skills are also transferable and consistently demanded by employers.

The Panel agreed on the importance of long-term, sustained investments focused on the goal of developing an educated labour force with the fundamental skills for STEM required to promote choice and flexibility. The Panel cautioned that a sole focus on practical, advanced, and otherwise specialized STEM skills development is a short-term policy response that may not maintain its relevance in the medium to long term. Beyond these investments, labour market information and natural labour market forces are expected to influence education and occupational decisions at the level of practical and advanced STEM skills.

8.4 WHAT IS KNOWN ABOUT THE RELATIVE IMPORTANCE OF DIFFERENT FACTORS AFFECTING CANADA'S SUPPLY OF STEM SKILLS, ESPECIALLY THROUGH THE CANADIAN LEARNING SYSTEM AND INTERNATIONAL MIGRATION?

Meeting future demands for workers with STEM skills can be achieved in three ways: entry from the domestic education system, improving the skills of current workers, and immigration. The Panel concluded that coordinated action on behalf of the education system, employers, and the immigration system is critical for meeting future STEM skill demands at all levels. The following response focuses on the first two factors (Section 8.2 has already addressed immigration).

The Canadian Education System

Because future demand for advanced STEM skills is difficult to predict, the Panel concluded that it is important to invest in the long-term goal of developing a STEM-literate society with a well-developed base of fundamental skills. Fundamental skills are the building blocks for all skills. Such skills are prerequisites for a number of future education and career pathways, and empower individuals with a range of options. They are important for all Canadians, regardless of occupation. Canadian students perform comparatively well on international tests of scientific and mathematical literacy, but there remain significant opportunities for improvement to increase the level of STEM skills among all learners, as well as to grow the talent pool of top performers.

Quality interventions are a significant factor in both of these endeavours, beginning at the pre-primary education level and continuing through secondary school. Strong foundations in STEM literacy (enabled by effective teachers, research-based pedagogical methods, and engaging instruction and curricular materials), coupled with support for early interventions that build on children's informal knowledge, are crucial aspects of developing a strong community of learners while challenging top students to excel academically. These fundamental skills form the basis for more complex STEM skills. Supports at each level are important to:

- develop the knowledge and skills of all students;
- mitigate early bottlenecks in the STEM skill supply;
- promote equity and excellence in education;
- enable a range of future opportunities for individuals; and,
- empower individuals to make informed choices.

Beyond preparing students for a range of future possibilities, the Panel emphasized the urgency of the opportunity to invest in developing fundamental skills for STEM, suggesting that early and sustained investments in STEM literacy may be one of a suite of components required to reverse Canada's poor innovation record.

While it is important for the general population to possess basic competency in STEM skills, this is not to suggest that everyone needs a post-secondary degree in a STEM field. Non-STEM skills, such as those acquired and used in the humanities, the arts, and social sciences, remain central to Canadian society. Furthermore, complementary skills, such as teamwork, leadership, entrepreneurship, and business acumen, represent life skills demanded (and rewarded) by employers. They may also be critical in the innovation process.

The number of post-secondary STEM graduates is not necessarily a useful indicator of supply. STEM education is a prerequisite for a number of STEM occupations, but Canadian data indicate that only 39% of employed STEM-educated individuals end up working in STEM-intensive occupations. Similarly, non-STEM degree-holders are found in even the most STEM-intensive occupations. Rather than indicating an oversupply of STEM graduates, the large proportion of STEM-educated individuals working in non-STEM professions may be due to the transferable nature of STEM degrees. In labour market terms, it is usually inefficient to allocate resources towards skills training that people will not use. However, through development of learning abilities and STEM competencies at the post-secondary level, individuals can acquire skills required to pursue work that is of interest to them and open doors to a range of future career options — even in changing labour market circumstances.

Employer-Sponsored Training

The Panel agreed that beyond preparing individuals for their first job, education should prepare individuals for life. This may include a lifetime of multiple careers. Employer-based training represents an important part of employee skills development; however, available data suggest that Canadian employees receive less workplace training than employees in many leading countries in Europe. This may limit the extent to which workers are able to gain experience and develop specialized skills to improve their own efficiency and their firm's productivity.

While post-secondary institutions are responsible for empowering students with a mix of theoretical, technical, and complementary knowledge and skills, educational institutions alone cannot be expected to train students for the range of tasks that they may encounter in professional environments. The Panel identified gaps in employer-sponsored training as a barrier to practical and advanced STEM skills development.

Flexibility in a range of education and training systems is likely to help equip the next generation of students with the STEM skills that they need as workers and as members of society. Some strategies, such as experiential learning, are able to bridge the divide between post-secondary education programs and employer-based training initiatives. They can also empower students with the complementary skills that are demanded by employers and that may help to maximize the impact of their practical and advanced STEM skills. *Collaboration and coordination among post-secondary institutions, government, industry, and community organizations are important to enable a range of options and skills and ongoing learning opportunities for students.*

Labour Force Growth Through Diversity

Support for under-represented populations in STEM education and careers is important for broadening Canada's STEM skill supply:

- Women represent 30% of individuals with a post-secondary STEM credential. Of this fraction of women, 27% are employed in a STEM-intensive occupation. The small proportion of women with STEM degrees persists despite an overall increase in the proportion of women with a post-secondary credential.
- As of 2011, about half of all Aboriginal people had a post-secondary qualification, compared with two-thirds of non-Aboriginal people.

- Representing about 50% of all STEM degree-holders, immigrants are a key source of STEM skills. However, immigrants often face lower employment rates and higher unemployment rates than native-born Canadians — even those with a STEM degree.

These differences are important because women, Aboriginal peoples, and immigrants tend to have lower incomes and poorer economic outcomes than men and Canadian-born workers overall. The existence of these gaps signals that Canada is not maximizing the full potential of its human capital, with potentially negative implications for innovation and productivity. For example, a mismatch exists between the large share of Aboriginal youth without paid employment (especially in the North) and employers struggling to develop sustainable local workforces. Taken together, these disparities are comprehensively documented as serious social, economic, and scientific concerns. Many opportunities exist for interventions to improve the participation of individuals from under-represented communities and widen the talent pool from which to draw. Again, early interventions to support diverse learners are critical, although opportunities for policy responses exist at multiple points.

8.5 MOVING FORWARD: IMPROVING DATA AND RESEARCH

Echoing conclusions from other experts (Drummond *et al.*, 2009; Drummond, 2014), the Panel identified key areas where higher-quality data and/or a greater quantity of data related to STEM skills and the labour market would be an asset to researchers, governments, individuals, industry, and post-secondary institutions (see Table 8.1).

Table 8.1

Improving Data and Research

Type of Data	Importance
Job vacancy data	Accurate job vacancy data are required to assess trends in filled and unfilled labour market demands and provide insight into areas of potential labour shortage or mismatch (StatCan, 2014m). In 2014, a new Quarterly Job Vacancy Survey was announced by ESDC. Conducted by Statistics Canada, it will collect data from up to 100,000 employers (compared with 15,000 under the current Job Vacancy Survey). Data will be available at the provincial/territorial level and Statistics Canada economic region, with estimates by occupation and skill level. The survey will be launched in Spring 2015 (ESDC, 2014e).
Wage data	Up-to-date wage information is important to get a clear picture of the prevailing wages paid to workers in different occupations and industries. ESDC announced a new National Wage Survey of up to 100,000 employers (compared with 56,000 households in previous surveys), to be launched in Spring 2015. The sample size will enable reliable disaggregation of data by province/territory and Statistics Canada economic region (ESDC, 2014e).

continued on next page

Type of Data	Importance
Transitions between education and the labour market	There are some data that link field of education to occupation and industry of employment. As presented in this report, however, access to such data is often limited to the highest credential level held by a person (which is not necessarily their most recent credential, or the one that is most relevant to their current employment). Full data sets exist with this information, but limited access rights represent an obstacle to research. The available data are often limited to time series with relatively few data points. Few standardized data exist on transitions between education programs in Canada, such as the number of students who change in or out of a STEM major, or move between universities and colleges.
Trend data	Significant changes in survey methods can affect the comparability of data over time. Methodological differences between the former long-form census (mandatory) with the NHS (voluntary) render data comparisons problematic, making it impossible to definitively determine whether differences in a variable are attributable to change or to non-response bias, for example (Giesbrecht, 2015). This change in data collection impeded the Panel's ability to examine longitudinal data for the purposes of their analyses.
Skills content of occupations	Most occupational data in Canada are organized by skill level (linked closely to educational requirements), with no detailed information about where various types of skills are used, or in greater demand, in the labour force. For example, the Panel found no available data or published analyses that could be used to assess whether skill requirements have changed over time, particularly for STEM skills.
Skills content of firms	There are no data available in Canada that would allow an analysis of the educational background of employees and firm-level performance in indicators such as growth, revenues, exports, innovation, or R&D activities. Data on the educational backgrounds and demographics of entrepreneurs and leaders of high-growth firms would provide researchers and policy-makers with additional insights about a highly productive subset.
Employer-based workplace training	Training data were formerly tracked through three Statistics Canada surveys, but the final year for which complete results were collected was 2005. Workplace training is a critical component of skills development, and accurate data would help to clarify and compare the extent to which employers are investing in employees.
Nature of offshoring and outsourcing activities	Although there is a general sense that much STEM work is easily offshored, both from and to Canada, there are no studies of STEM patterns in Canada. Some studies do provide insight into offshoring in certain industries, such as ICT (Baldwin & Gu, 2008; Mishagina, 2012).
Emigration of skilled workers	Canada has a strong body of data on immigration, but emigration statistics are difficult to track because departures are not documented as closely as arrivals (Eurostat, 2010). Canadian data are extremely limited, making it difficult to holistically assess the global flow of STEM skills.
Contribution of STEM skills to innovation, productivity, and growth	A handful of new studies suggest a strong positive spillover effect of immigrants with STEM skills on the productivity of metropolitan areas. However, the magnitude of this effect is uncertain, as is whether a similar effect can be expected from domestic production of workers with STEM skills.

High-quality labour market information is important for assessing labour market needs and matching skills with these needs. In general, more data are available on the supply of skills and labour in Canada than on the demand for skills in labour markets and sectors of the Canadian economy. Much of the available labour market information in Canada tracks outcomes such as earnings or employment. These are indicators of the results of supply and demand in the labour market, but a lack of vacancy data limits the ability of researchers and policy-makers to explain the observed outcomes.

Canada appears to lag behind countries such as the United Kingdom and United States in availability of labour market information, particularly types relevant to analyses of STEM and other skills. Several reports from both countries present in-depth analyses of STEM graduates and STEM workers. Data sets such as O*NET in the United States allow for analyses of skills content of occupations and workers beyond educational background, which are not available for Canada. The Panel noted that, with a few exceptions, much of the evidence cited in this report on the importance of STEM or high-level skills for innovation and productivity is based on analyses of U.S. data. The relative abundance of direct evidence from the United States and United Kingdom, and relative paucity of comparable studies on the Canadian labour market speaks to the relative quantity and detail of data available in Canada relative to peer countries. Further, while U.S. data are widely accessible, Canadian data are less available to the public, and therefore not as well studied.

8.6 FINAL REFLECTIONS

Many skills are required for success in the 21st century. A close analysis of STEM skills in Canada has revealed that a steady flow of STEM skills is important, but for slightly different reasons than common assumptions suggest. In response to the debate on the extent of current or imminent shortages of STEM workers, the evidence analyzed by the Panel suggests that currently, there is no national imbalance in workers with post-secondary education in a STEM field. Regional and sectoral-specific mismatches may still exist, but they are difficult to assess given data limitations. The Panel concluded that investments in practical and advanced STEM skills are best guided by medium- to long-term benefits, rather than short-term demands, which can change faster than large-scale investments can be adjusted. Further, the longevity and relevance of these specialized STEM skills may be compromised by constant changes in technology, which may profoundly alter the nature of work. A sole focus on practical and advanced STEM skills development is a short-term policy response that may not maintain its relevance in the medium to long term.

Nevertheless, the Panel strongly agreed that STEM skills are important for a number of reasons. In an uncertain future, a premium will be put on workers' adaptability. STEM skills give individuals tools that are critical to access a range of education and career options, even (and notably) in non-STEM fields such as reading and writing. Increasing the quality and level of fundamental skills for STEM among all learners at the preschool, primary, and secondary education levels represents a proactive, long-term approach to developing a skilled society that is prepared to respond to an uncertain future. Such a strategy would also give students the option to develop practical and advanced STEM skills. Fundamental skills for STEM open a variety of pathways and opportunities, and enable individuals to change course should the need arise.

Co-operation among those in education, immigration, government, and industry is essential if Canada is to nurture a skilled and adaptable society that is poised to meet current needs as well as future labour market demands. There are several opportunities for positive interventions to help Canadians develop the fundamental skills for STEM that are so important to a range of future options, to support basic research in STEM, to diversify education options and bridge the divide between classroom and on-the-job-training, and to promote ongoing skills development in workplaces. Together, we can ensure that Canadians are equipped with the skills needed for the jobs of today and tomorrow.

References

References

AANDC (Aboriginal Affairs and Northern Development Canada). (2013). Fact Sheet - 2011 National Household Survey. Aboriginal Demographics, Educational Attainment and Labour Market Outcomes. Retrieved October 2014, from https://www.aadnc-aandc.gc.ca/eng/1376329205785/1376329233875.

ABCLLC (ABC Life Literacy Canada). (2015). 9 Essential Skills. Retrieved January 2015, from http://abclifeliteracy.ca/nine-essential-skills.

Abele, F. & Delic, S. (2014). *Aboriginal Youth Employment in Northern Canada. Knowledge Synthesis Report – Draft.* Ottawa (ON): Social Sciences and Humanities Research Council.

Acemoglu, D. & Pischke, J.-S. (1999). Beyond Becker: Training in imperfect labour markets. *The Economic Journal, 109*(453 - Features), F112-F142.

Acemoglu, D. (2002). Technical change, inequality, and the labor market. *Journal of Economic Literature, 40*(1), 7-72.

Acemoglu, D. & Autor, D. (2010). Skills, tasks and technologies: Implications for employment and earnings. *National Bureau of Economic Research Working Paper Series, no. 16082.*

Actua. (2014). About Actua. Retrieved November 2014, from www.actua.ca.

Aghion, P. & Howitt, P. (1992). A model of economic growth through creative destruction. *Econometrica, 60*(2), 323-351.

Aghion, P. & Howitt, P. (1997). *Endogenous Growth Theory.* Cambridge (MA): The MIT Press.

Archambault, R. (1999). *New COPS Occupational Projection Methodology.* Hull (QC): Applied Research Branch, Human Resources Development Canada.

AUCC (Association of Universities and Colleges of Canada). (2007). *Canadian Universities and International Student Mobility.* Ottawa (ON): AUCC.

AUCC (Association of Universities and Colleges of Canada). (2009). *Earned Degrees.* Ottawa (ON): AUCC.

AUCC (Association of Universities and Colleges of Canada). (2011). *Trends in Higher Education. Vol. 1 - Enrolment.* Ottawa (ON): AUCC.

Autor, D. H., Katz, L. F., & Kearney, M. S. (2006). The polarization of the U.S. labor market. *American Economic Review Papers and Proceedings, 96*(2), 189-194.

Autor, D. H. (2013). The "task approach" to labor markets: An overview. *Journal for Labour Market Research, 46*(3), 185-199. doi: 10.1007/s12651-013-0128-z.

Autor, D. H. & Dorn, D. (2013). The growth of low-skill service jobs and the polarization of the U.S. labor market. *American Economic Review, 103*(5), 1553-1597. doi: 10.1257/aer.103.5.1553.

Bacolod, M. P., & Blum, B. S. (2010). Two sides of the same coin: US "residual" inequality and the gender gap. *Journal of Human Resources, 45*(1), 197-242.

Balcar, J. (2014). Soft skills and their wage returns: Overview of empirical literature. *Review of Economic Perspectives, 14*(1), 3-15.

Baldwin, J. R. & Gu, W. (2008). *Outsourcing and Offshoring in Canada. Catalogue no. 11F0027M — No. 055.* Ottawa (ON): Statistics Canada.

Baroody, A., Lai, M.-l., & Mix, K. (2006). The Development of Young Children's Early Number and Operation Sense and its Implications for Early Childhood Education. In B. Spodek & O. Saracho (Eds.), *Handbook of Research on the Education of Young Children* (2nd ed.). Mahwah (NJ): Lawrence Erlbaum Associates Publishers.

Barro, R. J. (2001). Human capital and growth. *American Economic Review, 91*(2), 12-17.

Bauernschuster, S., Falck, O., & Heblich, S. (2009). Training and innovation. *Journal of Human Capital, 3*(4), 323-353.

BCDD (Broadband Commission for Digital Development). (2014). *The State of Broadband 2014: Broadband for All.* Geneva, Switzerland: International Telecommunication Union and United Nations Educational, Scientific and Cultural Organization.

Beaudry, P., Green, D. A., & Sand, B. (2013). *The great reversal in the demand for skill and cognitive tasks. Working paper no. 18901.* The National Bureau of Economic Research.

Beede, D., Julian, T., Langdon, D., McKittrick, G., Khan, B., & Doms, M. (2011). *Women in STEM: A Gender Gap to Innovation. ESA Issue Brief #04-11.* Washington (DC): U.S. Department of Commerce.

Berkes, F. (2008). *Sacred Ecology* (2nd ed.). New York (NY): Routledge.

BIS (Department for Business, Innovation and Skills). (2013). *The Maturing of the MOOC: Literature Review of Massive Open Online Courses and Other Forms of Distance Learning. Research Paper no.130.* London, England: U.K. Government.

Bitran, M. & Tan, S. (2013). *Diaspora Nation: An Inquiry into the Economic Potential of Diaspora Networks in Canada.* Toronto (ON): Mowat Centre.

BLS (U.S. Bureau of Labor Statistics). (2014). Productivity: Labour Productivity – Business. Series ID PRS84006093. from http://beta.bls.gov/dataViewer/view/timeseries/PRS84006093.

Bocherby, S. & Buckner, L. (2012). *Women in Science, Technology, Engineering and Mathematics: from Classroom to Boardroom. U.S. Statistics 2012.* Leeds, United Kingdom: Women in Science, Technology, Engineering and Mathematics, University of Leeds.

Bonikowska, A., Green, D. A., & Riddell, C. (2008). *Literacy and the Labour Market: Cognitive Skills and Immigrant Earnings.* Ottawa (ON): Statistics Canada.

Borjas, G. & Doran, K. (2012). The collapse of the Soviet Union and the productivity of American mathematicians. *The Quarterly Journal of Economics, 127*(3), 1143-1203.

Boswell, C., Stiller, S., & Straubhaar, T. (2004). *Forecasting Labour and Skills Shortages: How Can Projections Better Inform Labour Migration Policies?* Hamburg Institute of International Economics, prepared for the EU, DG Employment and Social Affairs.

Bosworth, D., Lyonette, C., Wilson, R., Bayliss, M., & Fathers, S. (2013). *The Supply of and Demand for High-Level STEM Skills.* London, England: U.K. Commission for Employment and Skills.

Boudarbat, B. & Connolly, M. (2013). *Brain Drain: Why do Some Post-Secondary Graduates Choose to Work in the United States?* Montréal (QC): Centre interuniversitaire de recherche en analyse des organisations and Human Resources and Skills Development Canada.

Bougie, E., Kelly-Scott, K., & Arriagada, P. (2013). *The Education and Employment Experiences of First Nations People Living Off Reserve, Inuit, and Métis: Selected Findings From the 2012 Aboriginal Peoples Survey. Catalogue no. 11-001-X.* Ottawa (ON): Statistics Canada.

Brochu, P., Deussing, M.-A., Houme, K., & Chuy, M. (2013). *Measuring up: Canadian Results of the OECD PISA Study.* Toronto (ON): Council of Ministers of Education, Canada.

Bruce, C., Flynn, T., & Moss, J. (2012). *Math for Young Children (M4YC): Literature Review.* Toronto (ON): Trent University and University of Toronto.

Brynjolfsson, E. & McAfee, A. (2014). *The Second Machine Age: Work, Progress, and Prosperity in a Time of Brilliant Technologies.* New York (NY): W. W. Norton & Company, Inc.

Bussiere, P., Catwright, F., & Knighton, T. (2004). *Measuring up: Canadian Results of the OECD PISA Study The Performance of Canada's Youth in Mathematics, Reading, Science and Problem Solving.* Ottawa (ON): Human Resources and Skills Development Canada, Council of Ministers of Education, Canada and Statistics Canada.

Bussiere, P., Knighton, T., & Pennock, D. (2007). *Measuring up: Canadian Results of the OECD PISA Study. The Performance of Canada's Youth in Science, Reading and Mathematics.* Ottawa (ON): Human Resources and Social Development Canada, Council of Ministers of Education, Canada and Statistics Canada.

CAF (Canadian Apprenticeship Forum). (2011). *Investigating Apprenticeship Completion in Canada: Reasons for Non-Completion and Suggested Initiatives for Improving Completion.* Ottawa (ON): CAF.

CAF (Canadian Apprenticeship Forum). (2014). Apprenticeship in Canada. Retrieved September 2014, from http://caf-fca.org/index.php?page=apprenticeship-in-canada&hl=en_CA.

CanWIT (Canadian Women in Technology). (2014). About Us. Retrieved September 2014, from http://www.canwit.ca/about-us.

CAP (Congress of Aboriginal Peoples). (2010). *Staying in School: Engaging Aboriginal Students.* Ottawa (ON): CAP.

Card, D. & DiNardo, J. E. (2002). Skill biased technological change and rising wage inequality: Some problems and puzzles. *National Bureau of Economic Research Working Paper Series, no. 8769*.

Carey, D. (2014). *Overcoming Skills Shortages in Canada. OECD Economics Department Working Papers No. 1143*. Paris, France: OECD Publishing

Carnevale, A. P., Smith, N., & Melton, M. (2011). *STEM: Science, Technology, Engineering, Mathematics*. Washington (DC): Georgetown University Center on Education and the Workforce.

Casey, B. H. (2009). The economic contribution of PhDs. *Journal of Higher Education Policy and Management, 31*(3), 219-227.

CATAWIT (Canadian Advanced Technology Alliance Women in Technology Forum). (2010). *Addressing the Shortage of Women in ICT*. Ottawa (ON): Industry Canada.

CBoC (Conference Board of Canada). (2013). *How Canada Performs: A Report Card on Canada*. Ottawa (ON): Conference Board of Canada.

CBI (Confederation of British Industry and Pearson). (2013). *Changing the Pace: CBI/Pearson Education and Skills Survey 2013*: Confederation of British Industry and Pearson.

CBIE (Canadian Bureau for International Education). (2012). *A World of Learning: Canada's Performance and Potential in International Education*. Ottawa (ON): CBIE.

CCA (Council of Canadian Academies). (2009). *Innovation and Business Strategy: Why Canada Falls Short*. Ottawa (ON): The Expert Panel on Business Innovation, CCA.

CCA (Council of Canadian Academies). (2012a). *The State of Science and Technology in Canada, 2012*. Ottawa (ON): The Expert Panel on the State of Science and Technology in Canada, CCA.

CCA (Council of Canadian Academies). (2012b). *Strengthening Canada's Research Capacity: The Gender Dimension*. Ottawa (ON): The Expert Panel on Women in University Research, CCA.

CCA (Council of Canadian Academies). (2013a). *Innovation Impacts: Measurement and Assessment*. Ottawa (ON): The Expert Panel on the Socio-economic Impacts of Innovation Investments, CCA.

CCA (Council of Canadian Academies). (2013b). *The State of Industrial R&D in Canada*. Ottawa (ON): The Expert Panel on Industrial R&D, CCA.

CCA (Council of Canadian Academies). (2013c). *Paradox Lost: Explaining Canada's Research Strength and Innovation Weakness*. Ottawa (ON): Advisory Group, CCA.

CCA (Council of Canadian Academies). (2014). *Science Culture: Where Canada Stands*. Ottawa, ON: The Expert Panel on the State of Canada's Science Culture.

CCC (The Canadian Chamber of Commerce). (2013). *Upskilling the Workforce: Employer-Sponsored Training and Resolving the Skills Gap.* Toronto (ON): The Canadian Chamber of Commerce.

CCCE (Canadian Council of Chief Executives). (2014). *Preliminary Survey Report: The Skill Needs of Major Canadian Employers.* Ottawa (ON): CCCE.

CCL (Canadian Council on Learning). (2007a). *Canada's Biggest Economic Challenge: Improving Workplace Learning in Canada.* Ottawa (ON): CCL.

CCL (Canadian Council on Learning). (2007b). *Is it Possible to Accurately Forecast Labour Market Needs?* Ottawa (ON): CCL.

CCL (Canadian Council on Learning). (2010). *Availability of Workplace Training. 2010 Composite Learning Index Indicator Fact Sheets.* Ottawa (ON): CCL.

CERIC (Canadian Education and Research Institute for Counselling). (2014). *Career Development in the Canadian Workplace, National Business Survey.* Toronto (ON): Canadian Education and Research Institute for Counselling, Environics, and TD Bank.

Chaloff, J. & Lemaitre, G. (2009). *Managing Highly-Skilled Labour Migration: A Comparative Analysis of Migration Policies and Challenges in OECD Countries. OECD Social, Employment And Migration Working Papers N° 79.* Paris, France: OECD.

CHE (The Chronicle of Higher Education). (2012). *The Role of Higher Education in Career Development: Employer Perceptions.* Washington (DC): Chronicle-Marketplace.

CHE (The Chronicle of Higher Education). (2014). A College Degree Sorts Job Applicants, but Employers Wish it Meant More. Special Report. Retrieved March 2014, from http://chronicle.com/article/A-College-Degree-Sorts-Job/137625/#id=overview.

Christensen, C. (1997). *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail.* Boston (MA): Harvard Business Review Press.

CIC (Citizenship and Immigration Canada). (2012). *Canada Facts and Figures: Immigration Overview, Permanent and Temporary Residents.* Ottawa (ON): Government of Canada.

CIC (Citizenship and Immigration Canada). (2013). Study in Canada: Visas, Work and Immigration for International Students. Retrieved June 2014, from http://www.cic.gc.ca/English/resources/publications/study.asp.

CIC (Citizenship and Immigration Canada). (2014a). Backgrounder: Information for Applicants to the New Federal Skilled Worker Program. Retrieved June, 2014, from http://www.cic.gc.ca/english/department/media/backgrounders/2013/2013-04-18.asp?_ga=1.149959030.1596723051.1395757785#list.

CIC (Citizenship and Immigration Canada). (2014b). News Release: Attracting Skilled Newcomers to Canada. Retrieved September, 2014, from http://news.gc.ca/web/article-en.do?nid=826439.

CIC (Citizenship and Immigration Canada). (2015a). Six Selection Factors – Federal Skilled Workers Retrieved January 2015, from http://www.cic.gc.ca/english/immigrate/skilled/apply-factors.asp.

CIC (Citizenship and Immigration Canada). (2015b). Apply to Immigrate to Canada. Retrieved January 2015, from http://www.cic.gc.ca/english/immigrate/apply.asp.

Claessens, A. & Engel, M. (2013). How important is where you start? Early mathematics knowledge and later school success. *Teachers College Record, 115*, 1-29.

Clark, B. & Jurmain, M. (2014). *Evaluating Essential Skills for Ontario's Tradespeople (ESOT) Project.* Toronto (ON): Higher Education Quality Council of Ontario.

Clements, D. & Sarama, J. (2011). Early childhood mathematics intervention. *Science, 333*, 968-970.

CMEC (Council of Ministers of Education, Canada). (2013). *OECD Programme for the International Assessment of Adult Competencies. PIACC in Canada Slide Presentation.* Ottawa (ON): CMEC.

Cohen, M. S. & Zaidi, M. A. (2002). *Global Skill Shortages.* Northampton (MA): Edward Elgar Publishing.

Cowen, T. (2011). *The Great Stagnation: How America Ate All the Low-Hanging Fruit of Modern History, Got Sick, and Will (Eventually) Feel Better.* New York (NY): Dutton.

Cowen, T. (2013). *Average is Over: Powering America Beyond the Age of the Great Stagnation.* New York (NY): Dutton.

CP (Canadian Press). (2014). Canada Could Become Less Attractive to International Students. Retrieved January 2015, from http://www.macleans.ca/news/canada/canada-could-become-less-attractive-to-international-students/.

Cross, C., Woods, T., & Schweingruber, H. (Eds.). (2009). *Mathematics Learning in Early Childhood: Paths Toward Excellence and Equity.* Washington (DC): The National Academies Press.

CSE (Centre for Spatial Economics). (2008). *Future Labour Supply and Demand 101: A Guide to Analysing and Predicting Occupational Trends.* Milton (ON): CSE.

Cukier, W. (2009). *Attracting, Retaining and Promoting Women: Best Practices in the Canadian Tech Sector - Draft 2.* Ottawa (ON): Canadian Advanced Technology Alliance.

Davidson, P. & Soubry, P. (2014). What do Employers Want from Canadian Higher Education? Retrieved June 2014, from http://www.aucc.ca/media-room/news-and-commentary/employers-want-canadian-higher-education/.

Desai Trilokekar, R., Safdar, S., Al-Masri, A., & Scott, C. (2014). International Education, Future Citizens, and the Labour Market: Challenges and Prospects for Ontario. Retrieved July, 2014, from http://amiramasri.wix.com/international-ed.

Desjardins, L. & King, D. (2011). *Expectations and Labour Market Outcomes of Doctoral Graduates from Canadian Universities.* Ottawa (ON): Statistics Canada.

DeVoretz, D. & Ma, J. (2002). Triangular human capital flows between sending, entrepot and the rest of the world regions. *Canadian Studies in Population, Special Issue on Migration and Globalization, 29*(1), 53-69.

DeVoretz, D. (2006). The education, immigration and emigration of Canada's highly skilled workers in the 21st century. *Research on Immigration and Integration in the Metropolis. Working Paper Series, 6*(16), 1-67.

DFAIT (Department of Foreign Affairs and International Trade). (2012). *International Education: A Key Driver of Canada's Future Prosperity.* Ottawa (ON): Advisory Panel on Canada's International Education Strategy.

DFATD (Department of Foreign Affairs, Trade and Development Canada). (2014). *Canada's International Education Strategy.* Ottawa (ON): Government of Canada.

Dion, N. (2014). *Emphasizing Numeracy as an Essential Skill.* Toronto (ON): Higher Education Quality Council of Ontario.

Dion, P. & Vezina, M. (2014). *Emigration from Canada to the United States from 2000 to 2006.* Ottawa (ON): Statistics Canada.

DIUS (Department for Innovation, Universities & Skills). (2009). *The Demand for Science, Technology, Engineering and Mathematics (STEM) Skills.* London, UK: U.K. Government.

Docquier, F., Ozden, C., & Peri, G. (2013). The labour market effects of immigration and emigration in OECD countries. *The Economic Journal, 124*(579), 1106-1145. doi: 10.1111/ecoj.12077.

Donahoe, D. (2013). The Definition of STEM? Retrieved July 2014, from http://www.todaysengineer.org/2013/Dec/STEM-definition.asp.

Donofrio, N., Spohrer, J., & Zadeh, H. S. (2009). Research-Driven Medical Education and Practice: A Case for T-Shaped Professional. *Medical Journal of Australia: Viewpoint,* 1-6.

Dostie, B. (2010). *Scientific Series: Estimating the Returns to Firm-Sponsored on-the-job and Classroom Training.* Montréal (QC): CIRANO.

Dostie, B. (2014). Innovation, productivity, and training. *IZA Discussion Paper, No. 8506,* 1-37.

Drummond, D., Beale, E., Kolby, K., Loiselle, M., & Miner, R. (2009). *Working Together to Build a Better Labour Market Information System for Canada.* Ottawa (ON): Advisory Panel on Labour Market Information, Forum of Labour Market Ministers.

Drummond, D. & Fong, F. (2010). An Economics Perspective of Canadian Immigration, *Policy Options,* July-August 2010.

Drummond, D. (2014). *Wanted: Good Canadian Labour Market Information.* Montréal (QC): Institute for Research on Public Policy.

Duggar, W. E. (2010). *Evolution of STEM in the United States.* Paper presented at 6th Biennial International Conference on Technology Education Research, Australia.

Dumont, J.-C. & Lemaitre, G. (2005). *Counting Immigrants and Expatriates in OECD Countries: A New Perspective. OECD Social, Employment and Migration Working Papers, no. 25.* Paris, France: OECD.

Duncan, G., Claessens, A., Huston, A., Pagani, L., Engel, M., Sexton, H., … Japen, C. (2007). School readiness and later achievement. *Developmental Psychology, 43*(6), 1428-1446.

EPSSO (Expert Panel on Student Success in Ontario). (2004). *Leading Math Success: Mathematical Literacy Grades 7-12.* Toronto (ON): Government of Ontario.

ESDC (Employment and Skills Development Canada). (2014a). *Overhauling the Temporary Foreign Worker Program.* Ottawa (ON): Government of Canada.

ESDC (Employment and Social Development Canada). (2014b). Funding: Literacy and Essential Skills. Retrieved March 2014, from http://www.esdc.gc.ca/eng/jobs/les/funding/index.shtml.

ESDC (Employment and Social Development Canada). (2014c). Canadian Occupational Projection System 2013 Projections: Imbalances Between Labour Demand and Supply 2013-2022. Retrieved September 2014, from http://www23.hrsdc.gc.ca/l.3bd.2t.1ilshtml@-eng.jsp?lid=29&fid=1&lang=en.

ESDC (Employment and Social Development Canada). (2014d). Aboriginal Skills and Employment Training Strategy. Retrieved January 2015, from http://www.esdc.gc.ca/eng/jobs/aboriginal/asets/index.shtml.

ESDC (Employment and Social Develpment Canada). (2014e). Better and More Labour Market Information. Retrieved October 2014, from http://www.esdc.gc.ca/eng/jobs/foreign_workers/reform/improve.shtml.

Eurostat (United Nations Economic Commission for Europe Statistical Office of the European Union). (2010). *Guidelines for Exchanging Data to Improve Emigration Statistics.* Geneva, Switzerland: United Nations.

Eurostat. (2014a). HRST by Sub-groups, Sex and Age. Persons with Tertiary Education (ISCED) and Employed in Science and Technology. Retrieved July 2014, from http://appsso.eurostat.ec.europa.eu/nui/show.do.

Eurostat. (2014b). Labour Productivity - Annual Data. Real Labour Productivity per Hour Worked. Retrieved July 2014, from http://appsso.eurostat.ec.europa.eu/nui/show.do.

Fang, T. (2009). Workplace responses to vacancies and skill shortages in Canada. *International Journal of Manpower, 30*(4), 326-348. doi: 10.1108/01437720910973034.

FC (Finance Canada). (2004). *Budget 2004: Budget Plan. The Importance of Productivity Growth to the Long-Term Well-Being of Canadians.* Ottawa (ON): Governent of Canada.

Ferrer, A., Green, D. A., & Riddell, C. (2006). The effect of literacy on immigrant earnings. *The Journal of Human Resources, 41*(2), 380-410.

Ferrer, A., Picot, G., & Riddell, C. (2014). New directions in immigration policy: Canada's fresh approach to immigrant selection. *International Migration Review, 48*(Fall), 846-847.

Finn, M. G. (2014). *Stay Rates of Foreign Doctorate Recipients from U.S. Universities, 2011.* Washington (DC): National Center for Science and Engineering Statistics.

Finnie, R. & Childs, S. (2014). Post-Schooling Outcomes of University Graduates: A Tax Data Linkage Approach. Ottawa (ON): Education Policy Research Initiative, University of Ottawa.

Foster, J. (2012). Making temporary permanent: The silent transformation of the Temporary Foreign Worker Program. *Just Labour: A Canadian Journal of Work and Society, 19*(Autumn), 22-46.

Freeman, R. B. (2006). Is a great labour shortage coming? Replacement demand in the global economy. *National Bureau of Economic Research Working Paper Series, 12541.*

Frenette, M. (2014). *An Investment of a Lifetime? The Long-term Labour Market Premiums Associated with a Postsecondary Education.* Ottawa (ON): Statistics Canada.

Frey, C. B. & Osborne, M. A. (2013). The Future of Employment: How Susceptible Are Jobs to Computerisation? Retrieved February 2014, from http://www.oxfordmartin.ox.ac.uk/downloads/academic/The_Future_of_Employment.pdf.

Frize, M. (2009). *The Bold and the Brave: A History of Women in Science and Engineering.* Ottawa (ON): University of Ottawa Press.

Gal, I. & Tout, D. (2014). Comparison of PIAAC and PISA frameworks for numeracy and mathematical literacy. *OECD Education Working Papers*(102).

GAO (United States Government Accountability Office). (2014). *Science, Technology, Engineering, and Mathematics Education: Assessing the Relationship between Education and the Workforce.* Washington (DC): United States GAO.

Giesbrecht, W. (2015). Data & Statistics: National Household Survey. Retrieved January 2015, from http://researchguides.library.yorku.ca/nhs#dataquality.

Gingras, Y. & Roy, R. (2000). Is there a skill gap in Canada? *Canadian Public Policy, 26*(Supplement 1), S159-S174.

Ginsburg, H., Lee, J. S., & Boyd, J. S. (2008). Mathematics education for young children: What it is and how to promote it. *Social Policy Report, 22*(1), 3-23.

Gonzalez, H. B. & Kuenzi, J. J. (2012). *Science, Technology, Engineering, and Mathematics (STEM) Education: A Primer.* Washington (DC): Congressional Research Service.

GQ (Gouvernement du Quebec). (2014). An Act to Promote Workforce Skills Development and Recognition. Retrieved July, 2014, from http://www2.publicationsduquebec.gouv.qc.ca/dynamicSearch/telecharge.php?type=2&file=/D_8_3/D8_3_A.html.

Green, A. G. & Green, D. A. (1999). The economic goals of Canada's immigration policy: Past and present. *Canadian Public Policy, 25*(4), 425-451. doi: 134.117.10.200.

Green, D. A. & Sand, B. (2014). Has the Canadian labour market polarized? *Canadian Labour Market and Skills Researcher Network Working Papers. no. 133*, 1-46.

Greenwood, C., Harrison, M. & Vignola, A. (2011). *The Labour Market Value of STEM Qualifications and Occupations. An Analysis for the Royal Academy of Engineering*. London, England: Department of Quantitative Social Science, Institute of Education.

Griffith, A. (2014). The New Citizenship Act is Efficient. Is it Fair? Retrieved January 2015, from http://www.ipolitics.ca/2014/06/18/the-new-citizenship-act-is-efficient-is-it-fair/.

Griliches, Z. (1990). Patent statistics as economic indicators: A survey. *Journal of Economic Literature, 28*(4), 1661-1707.

Griliches, Z. (1992). The search for R&D spillovers. *Scandinavian Journal of Economics, 94*(Supplement), 29-47.

Gross, D. (2014). *Temporary Foreign Workers in Canada: Are They Really Filling Labour Shortages?* Toronto (ON): C.D. Howe Institute.

Haelermans, C. & Borgans, L. (2011). *Wage Effects of On-The-Job Training: A Meta-Analysis. ROA Research Memorandum. ROA-RM-2011/11.* Maastricht, The Netherlands: Maastricht University, Research Centre for Education and the Labour Market.

Hango, D. (2013). *Gender Differences in Science, Technology, Engineering, Mathematics and Computer Science (STEM) Programs at University. Catalogue no. 75-006-X.* Ottawa (ON): Statistics Canada.

Hango, D. (2014). *University Graduates with Lower Levels of Literacy and Numeracy Skills. Catalogue no. 75-006-X.* Ottawa (ON): Statistics Canada.

Hansen, J. (2010). How does academic ability affect educational and labour market pathways in Canada. *OECD Education Papers*(30).

Hanushek, E. A. & Woessmann, L. (2012). Do Better Schools Lead to More Growth? Cognitive Skills, Economic Outcomes, and Causation. *Journal of Economic Growth, 17*(4), 267-321.

Hanushek, E. A. (2013). Economic Growth in Developing Countries: The Role of Human Capital. *Economics of Education Review, 37*, 204-212.

Hatcher, A. & Bartlett, C. (2010). Two-eyed seeing: Building cultural bridges for Aboriginal students. *Canadian Teacher Magazine* (May 2010), 14-17.

Head, K., Ries, J., & Swenson, D. (1999). Attracting foreign manufacturing: Investment promotion and agglomeration. *Regional Science and Urban Economics*(29), 197-218.

Heckman, J. (2008). *Schools, Skills, and Synapses. Discussion paper no. 3515.* Bonn, Germany: Institute for the Study of Labor (IZA).

Heckman, J. (2014). Invest in Early Childhood Development: Reduce Deficits, Strengthen the Economy. Retrieved August 2014, from http://heckmanequation.org/content/resource/invest-early-childhood-development-reduce-deficits-strengthen-economy.

Hembree, R. (1990). The nature, effects and relief of mathematics anxiety. *Journal for Research in Mathematics Education, 21*(1), 33-46.

Hewlett, S., Buck Luce, S., Servon, L., Sherbin, L., Shiller, P., Sosnovich, E., & Sumberg, K. (2008). *The Athena Factor: Reversing Brain Drain in Science, Engineering, and Technology. Harvard Business Review Research Report. Product no. 10094.* New York (NY): Center for Work-Life Policy.

Hill, C., Corbett, C., & St. Rose, A. (2010). *Why So Few? Women in Science, Technology, Engineering, and Mathematics.* Washington (DC): American Association of University Women.

Hooker, H. & Achur, J. (2014). *First findings from the UK Innovation Survey 2013.* London, England: Department for Business, Innovation and Skills, UK Government.

HRSDC (Employment and Social Development Canada). (2009a). *Summative Evaluation of the Aboriginal Human Resources Development Agreements. Final Report.* Ottawa (ON): Government of Canada.

HRSDC (Employment and Social Development Canada). (2009b). *Formative Evaluation of the Aboriginal Human Resources Development Agreements.* Ottawa (ON): Government of Canada.

HRSDC, IC, & SSHRC (Human Resources and Social Development Canada, Industry Canada, Social Sciences and Humanities Research Council). (2008). *Adjustments in Markets for Skilled Workers in Canada: A Synthesis of Key Findings and Policy Implications.* Ottawa (ON): Government of Canada.

Hughes, G. (1993). *Projecting the Occupational Structure of Employment in OECD Countries.* Paris, France: OECD.

Hunt, J. & Gauthier-Loiselle, M. (2010). How much does immigration boost innovation? *American Economic Journal: Macroeconomics, 2*(April), 31-56.

IEA (International Association for the Evaluation of Educational Achievement). (2011). TIMSS 2011. Retrieved February, 2014, from http://www.iea.nl/timss_2011.html.

ITEA (International Technology Education Association). (2007). *Standards for Technological Literacy: Content for the Study of Technology.* Reston (VA): ITEA.

ITEEA (International Technology and Engineeting Educators Association). (2011). I^3 Project: Invention-Innovation-Inquiry. Retrieved August, 2014, from http://www.iteea.org/i3/index.htm.

Jones, C. (1995). Time series tests of endogenous growth models. *Quarterly Journal of Economics, 100*, 495-525.

Jones, C. (2002). Sources of US Economic Growth in a World of Ideas. *American Economic Review, 92*(1), 220-239.

Jordan, N., Kaplan, D., Ramineni, C., & Locuniak, M. (2009). Early math matters: Kindergarten number competence and later mathematics outcomes. *Developmental Psychology, 45*(3), 850-867.

Junge, M., Severgnini, B., & Sorensen, A. (2013). *Evidence on the Impact of Education on Innovation and Productivity.* Paper presented at European Economic Association & Econometric Society 2013 Parallel Meetings, Gothenburg, Sweden.

Katz, L. F. & Autor, D. (1999). Changes in the Wage Structure and Earnings Inequality. In O. Ashenfelter & D. Card (Eds.), *Handbook of Labor Economics.* Amsterdam, North-Holland: Elsevier.

Kautz, T., Heckman, J., Diris, R., Weel, B., & Borghans, L. (2014). *Fostering and Measuring Skills: Improving Cognitive and Non-Cognitive Skills to Promote Lifetime Success. OECD Education Working Papers, no. 110.* Paris, France: OECD Publishing.

Kelly, D., Azoulay, A., Debus, A., George, B., Parent, L.-M., Petkov, P., & Tilley, H. (n.d.). *Canada's Training Ground: SMEs' $18 Billion Investment in the Nation's Workforce.* Toronto (ON): Canadian Federation of Independent Business.

Kerr, W. & Lincoln, W. (2010). The supply side of innovation: H-1B visa reforms and U.S. ethnic invention. *Journal of Labor Economics, 28*(3), 473-508.

Knighton, T., Hujaleh, F., Iacampo, J., & Werkneh, J. (2009). *Lifelong Learning Among Canadians Aged 18 to 64 Years: First Results from the 2008 Access and Support to Education and Training Survey. Catalogue no. 81-595-M No. 079.* Ottawa (ON): Statistics Canada.

Knighton, T., Brochu, P., & Gluzynski, T. (2010). *Measuring up: Canadian Results of the OECD PISA Study. The Performance of Canada's Youth in Reading, Mathematics and Science.* Ottawa (ON): Human Resources and Skills Development Canada, Council of Ministers of Education, Canada and Statistics Canada.

Koedel, C. & Tyhurst, E. (2012). Math skills and labor-market outcomes: Evidence from a resume-based field experiment. *Economics of Education Review, 31*(1), 131-140.

Kramer, M. & Usher, A. (2011). *Work-Integrated Learning and Career-Ready Students: Examining the Evidence.* Toronto (ON): Higher Education Strategy Associates.

Krug, D. (2012). *STEM Education and Sustainability in Canada.* Paper presented at 2nd International STEM in Education Conference, Beijing, China.

Landivar, L. (2013). *The Relationship Between Science and Engineering Education and Employment in STEM Occupations.* Washington (DC): United States Census Bureau.

Langdon, D., McKittrick, G., Beede, D., Khan, B., & Doms, M. (2011). *STEM: Good Jobs Now and for the Future.* Washington (DC): Economics and Statistics Administration, U.S. Department of Commerce.

Laporte, C. & Mueller, R. (2011). *The Completion Behaviour of Registered Apprentices: Who Continues, Who Quits, and Who Completes Programs? Catalogue no. 11F0019M — no. 333.* Ottawa (ON): Statistics Canada.

Laporte, C. & Mueller, R. (2012). *Certification, Completion, and the Wages of Canadian Registered Apprentices. Catalogue no. 11F0019M — no. 345.* Ottawa (ON): Statistics Canada.

Lavis, L. (2011). *Learning and Development Outlook 2011: Are Organizations Ready for Learning 2.0?* Ottawa (ON): The Conference Board of Canada.

Lee, J., Kotsopoulos, D., & Zambrzycka, J. (2012). *Does Block Play Support Children's Numeracy Development?* Paper presented at Navigating Transitions Along Continuums: Proceedings. Thirty-Fourth Annual Meeting of the North American Chapter of the International Group for the Psychology of Mathematics Education, Kalamazoo (MI).

Lefebvre, R., Simonova, E., & Wang, L. (2012). *Issue in Focus: Labour Shortages in Skilled Trades – The Best Guestimate?* Ottawa (ON): Certified General Accountants – Canada.

Lerman, R. (2014). *Expanding Apprenticeship in Canada: Perspectives from International Experience.* Ottawa (ON): Canadian Council of Chief Executives.

Loppie Reading, C. & Wien, F. (2009). *Health Inequalities and Social Determinants of Aboriginal People's Health.* Prince George (BC): National Collaborating Centre for Aboriginal Health.

Lowell, B. L. & Salzman, H. (2007). *Into the Eye of the Storm: Assessing the Evidence on Science and Engineering Education, Quality, and Workforce Demand.* Washington (DC): The Urban Institute.

MaRS (MaRS Discovery District). (2013). *MaRS Venture Surveys.* Toronto (ON): MaRS.

Mas, S. (2014). Canada Job Grant Won't be in Place July 1 in Most Provinces. Retrieved September, 2014, from http://www.cbc.ca/news/politics/canada-job-grant-won-t-be-in-place-july-1-in-most-provinces-1.2690173.

McDaniel, S. A., Watt-Malcolm, B., & Wong, l. (2014). *Is the Math Sufficient? Aging Workforce and the Future Labour Market in Canada.* Ottawa (ON): Social Sciences and Humanities Research Council (SSHRC).

McHale, J. (2010). Structural Incentives to Attract Foreign Students to Canada's Postsecondary Educational System: A Comparative Analysis. In R. Bhandari & P. Bluemthal (Eds.), *International Students and Global Mobility in Higher Education: National Trends and New Directions* New York (NY): Palgrave MacMillan.

Meagher, G. A. & Pang, F. (2011). *Labour Market Forecasting, Reliability and Workforce Development.* Clayton, Australia: Centre of Policy Studies, Monash University.

Midgley, C., Feldlaufer, H., & Eccles, J. S. (1989). Student/teacher relations and attitudes toward mathematics before and after the transition to junior high school. *Child Development, 60*(4), 981-992.

Mincer, J. (1958). Investment in human capital and personal income distribution. *Journal of Political Economy, 66*(4), 281-302.

Miner, R. (2010). *People Without Jobs, Jobs Without People: Ontario's Labour Market Future.* Toronto (ON): Miner Management Consultants.

Mishagina, N. (2012). *The State of STEM Labour Markets in Canada Literature Review.* Montréal (QC): Centre interuniversitaire de recherche en analyse des organisations.

MOE & DSBs (Ontario Ministry of Education, Dufferin Peel Catholic DSB, Peel DSB, Upper Grand DSB, Waterloo Region DSB, York Region DSB). (2005). *TIPS for English Language Learners in Mathematics: Grade 7, Grade 8, Grade 9 Applied, and Grade 10 Applied.* Toronto (ON): Government of Ontario.

Moon, J. & Singer, S. R. (2012). Bringing STEM into focus. *Education Week, 31*(19).

Morissette, R., Chan, P., & Lu, Y. (2013). *Wages, Youth Employment, and School Enrollment: Recent Evidence from Increases in World Oil Prices.* Ottawa (ON): Statistics Canada, Social Analysis Division.

Moser, P., Voena, A., & Waldinger, F. (2014). German-Jewish emigres and U.S. invention. *National Bureau of Economic Research Working Paper Series, Working Paper no. 19962*, 1-59.

NAS (National Academy of Sciences, National Academy of Engineering, and Institute of Medicine of the National Academies). (2007). *Beyond Bias and Barriers: Fulfilling the Potential of Women in Academic Science and Engineering.* Washington (DC): National Academies Press.

NAS (National Academy of Sciences). (2013). *The Mathematical Sciences in 2025.* Washington (DC): Committee on the Mathematical Sciences in 2025; Board on Mathematical Sciences and Their Applications; Division on Engineering and Physical Sciences; National Research Council.

NMAP (National Mathematics Advisory Panel). (2008). *Foundations for Success: The Final Report of the National Mathematics Advisory Panel.* Washington (DC): U.S. Department of Education.

NMAP, Ball, D. L., Simons, J., Wu, H.-H., Simon, R., Whitehurst, G. J. R., & Yun, J. (National Mathematics Advisory Panel). (2008). *Chapter 5: Report of the Task Group on Teachers and Teacher Education.* Washington (DC): U.S. Department of Education.

NRC (National Research Council). (2011). *Successful K-12 STEM Education. Identifying Effective Approaches in Science, Technology, Engineering, and Mathematics.* Washington (DC): The National Academies Press.

Nye, B., Konstantopolous, S., & Hedges, L. (2004). How large are teacher effects? *Educational Evaluation and Policy Analysis, 26*(3), 237-257.

OECD (Organisation for Economic Co-operation and Development). (2009). *PIAAC Numeracy: A Conceptual Framework.* Paris, France: OECD Publishing.

OECD (Organisation for Economic Co-operation and Development). (2010). Finland: Slow and Steady Reform for Consistently High Results. In OECD (Ed.), *Strong Performers and Successful Reformers in Education: Lessons From PISA for the United States.* Paris, France: OECD Publishing.

OECD (Organisation for Economic Co-operation and Development). (2011a). *Education at a Glance, 2011: Education Indicators.* Paris, France: OECD Publishing.

OECD (Organisation for Economic Co-operation and Development). (2011b). *Education at a Glance, 2011: Glossary.* Paris, France: OECD Publishing.

OECD (Organisation for Economic Co-operation and Development). (2012a). *Better Skills, Better Jobs, Better Lives. A Strategic Approach to Skills Policies.* Paris, France: OECD Publishing.

OECD (Organisation for Economic Co-operation and Development). (2012b). *Literacy, Numeracy and Problem Solving in Technology-Rich Environments: Framework for the OECD Survey of Adult Skills.* Paris, France: OECD Publishing.

OECD (Organisation for Economic Co-operation and Development). (2012c). *OECD Economic Surveys: Canada 2012.* Paris, France: OECD Publishing.

OECD (Organisation for Economic Co-operation and Development). (2013a). *OECD Science, Technology and Industry Scoreboard 2013.* Paris, France: OECD Publishing.

OECD (Organisation for Economic Co-operation and Development). (2013b). *Education at a Glance 2013. Country Note: Canada.* Paris, France: OECD Publishing.

OECD (Organisation for Economic Co-operation and Development). (2013c). *Researchers on the Move: The Impact of Brain Circulation.* Paris, France: OECD Directorate for Science, Technology, and Industry.

OECD (Organisation for Economic Co-operation and Development). (2013d). *PISA 2012 Results: What Makes Schools Successful? Resources, Policies and Practices (Volume IV).* Paris, France: OECD Publishing.

OECD (Organisation for Economic Co-operation and Development). (2013e). *International Migration Outlook 2013.* Paris, France: OECD Publishing.

OECD (Organisation for Economic Co-operation and Development). (2013f). *Education at a Glance 2013: OECD Indicators.* Paris, France: OECD Publishing.

OECD (Organisation for Economic Co-operation and Development). (2014a). OECD Education Database: Graduates by Field of Education. Retrieved January, 2015, from http://stats.oecd.org/viewhtml.aspx?datasetcode=RGRADSTY&lang=en#.

OECD (Organisation for Economic Co-operation and Development). (2014b). Population Statistics. Retrieved January, 2015, from http://stats.oecd.org.proxy2.library.mcgill.ca/index.aspx?DataSetCode=POP_FIVE_HIST.

OECD (Organisation for Economic Co-operation and Development). (2014c). About PISA. Retrieved November 2014, from http://www.oecd.org/pisa/aboutpisa.

OECD (Organisation for Economic Co-operation and Development). (2014d). *PISA 2012 Results: What Students Know and Can Do - Student Performance in Mathematics, Reading and Science (Volume 1, Revised edition, February 2014).* Paris, France: OECD Publishing.

OECD (Organisation for Economic Co-operation and Development). (2014e). *PISA 2012 Results: Creative Problem Solving: Students' Skills in Tackling Real-Life Problems.* Vol. 5. Paris, France: OECD Publishing.

OECD (Organisation for Economic Co-operation and Development). (2014f). *PISA 2012 Results in Focus: What 15 Year Olds Know and What They Can Do With What They Know.* Paris, France: OECD Publishing.

OECD (Organisation for Economic Co-operation and Development). (2014g). *PISA in Focus 36. Do Parents' Occupations Have an Impact on Student Performance?* Paris, France: OECD Publishing.

OECD (Organisation for Economic Co-operation and Development). (2015). OECD StatExtracts. Growth in GDP per Capita, Productivity and ULC: Growth in GDP per Capita and Labour Productivity. Retrieved February 2015, from http://stats.oecd.org/index.aspx?queryid=54564.

OECD/Eurostat (Organisation for Economic Co-operation and Development). (2005). *Oslo Manual: Guidelines for Collecting and Interpreting Innovation Data. 3rd Ed.* Paris, France: OECD and Eurostat.

Office of the Chief Scientist. (2013). *Science, Technology, Engineering and Mathematics in the National Interest: A Strategic Approach.* Canberra, Australia: Australian Government.

Orpwood, G., Schmidt, B., & Jun, H. (2012). *Competing in the 21st Century Skills Race.* Ottawa (ON): Canadian Council of Chief Executives.

Orser, B., Riding, A., & Stanley, J. (2012). Perceived career challenges and response strategies of women in the advanced technology sector. *Entrepreneurship & Regional Development, 24*(1-2), 73-93.

Pascal, C. (2009). *With Our Best Future in Mind: Implementing Early Learning in Ontario. Report to the Premier by the Special Advisor on Early Learning.* Toronto (ON): Government of Ontario.

PE (People for Education). (2013). *Broader Measures of School Success: Measuring What Matters.* Toronto (ON): People for Education.

PEA (Prism Economics and Analysis). (2012). *The Engineering Labour Market in Canada: Projections to 2020.* Ottawa (ON): Engineers Canada.

Pellegrino, J. W., & Hilton, M. L. (2013). *Education for Life and Work: Developing Transferable Knowledge and Skills in the 21st Century.* Washington (DC): National Academies Press.

Peri, G. & Shih, K. (2013). *Foreign Scientists and Engineers and Economic Growth in Canadian Labor Markets.* Bonn, Germany: Institute for the Study of Labour. IZA Discussion Paper, no. 7367.

Peri, G., Shih, K., & Sparber, C. (2014). *Foreign STEM Workers and Native Wages and Employment in U.S. Cities.* Cambridge (MA): National Bureau of Economic Research, Working Paper no. 20093.

Perry, B. & Dockett, S. (2008). Young Children's Access to Powerful Mathematical Ideas. In L. English (Ed.), *Handbook of International Research in Mathematics Education* (2nd ed.). New York (NY): Routledge.

Peters, J. (2012). *Faculty Experiences with and Perceptions of Work-Integrated Learning (WIL) in the Ontario Postsecondary Sector.* Toronto (ON): Higher Education Quality Council of Ontario.

Picot, G. & Sweetman, A. (2005). *The Deteriorating Economic Welfare of Immigrants and Possible Causes.* Ottawa (ON): Statistics Canada.

Picot, G. & Hou, F. (2012). *Immigrant Status, Early Skill Development, and Postsecondary Participation: A Comparison of Canada and Switzerland. Catalogue no. 11F0019M — No. 344.* Ottawa (ON): Statistics Canada.

Plesca, M. & Summerfield, F. (2014). *Skill Demand, Supply, and Mismatch in the Canadian Economy: Knowledge Synthesis Report.* Ottawa (ON): Social Sciences and Humanities Research Council (SSHRC).

Polgreen, L. & Silos, P. (2009). Crude substitution: the cyclical dynamics of oil prices and the skill premium. *Journal of Monetary Economics, 56*(3), 409-418.

Powell, A., Bagihole, B., Dainty, A., & Neale, R. (2004). Does the engineering culture in UK higher education advance women's careers? *Equal Opportunities International, 23*(7/8), 21-38.

PPF (Public Policy Forum). (n.d.). *Apprenticeship in Canada, a Public - Private Sector Partnership.* Ottawa, ON: PPF.

Rao, S., Ahmad, A., Horsman, W., & Kaptein-Russell, P. (2001). *The Importance of Innovation for Productivity.* Ottawa (ON): Industry Canada.

Richards, J. & Scott, M. (2009). *Aboriginal Education: Strengthening the Foundations.* Ottawa (ON): Canadian Policy Research Networks.

Richards, J. (2014). *Are We Making Progress? New Evidence on Aboriginal Education Outcomes in Provincial and Reserve Schools. Commentary no. 408.* Toronto (ON): C.D. Howe Institute.

Richardson, S. (2007). *What Is a Skill Shortage?* Adelaide, Australia: The National Centre for Vocational Education Research (NCVER).

Richardson, S. & Tan, Y. (2007). *Forecasting Future Demands: What We Can and Cannot Know.* Adelaide, Australia: National Centre for Vocational Education Research (NCVER) on behalf of the Austalian Government.

Riddell, W. C. & Song, X. (2009). *The Causal Effects of Education on Adaptability to Employment Shocks: Evidence from the Canadian Labour Market.* Vancouver (BC): Canadian Labour Market and Skills Researcher Network.

Rivkin, S. G., Hanushek, E. A., & Kain, J. F. (2005). Teachers, schools and academic achievement. *Econometrica, 73*(2), 417-458.

Robst, J. (2007). Education, college major, and job match: Gender differences in reasons for mismatch. *Education Economics, 15*(2), 159-175. doi: 10.1080/09645290701263070.

Rothwell, J. (2013). *The Hidden STEM Economy*. Washington (DC): The Brookings Institution.

RQ (Revenu Quebec). (2012). Contribution to the Workforce Skills Development and Recognition Fund (WSDRF). Retrieved July 2014, from http://www.revenuquebec.ca/en/entreprise/retenues/methode_calcul/formation.aspx.

Sahlberg, P. (2011). *Finnish Lessons: What Can the World Learn from Educational Change in Finland?* New York (NY): Teacher's College Press.

Sahlberg, P. (2013). What if Finland's Great Teachers Taught in U.S. Schools? Retrieved May 2014, from http://m.washingtonpost.com/blogs/answer-sheet/wp/2013/05/15/what-if-finlands-great-teachers-taught-in-u-s-schools-not-what-you-think/

Salzman, H. & Lowell, L. (2008). Making the grade. *Nature, 453*(7191), 28-30. doi: 10.1038/453028a.

Salzman, H. (2013). What shortages? The real evidence about the STEM workforce. *Issues in Science and Technology, Summer*, 58-67.

Salzman, H., Kuehn, D., & Lowell, B. L. (2013). *Guestworkers in the High-Skill U.S. Labor Market: An Analysis of Supply, Employment, and Wage Trends.* Washington (DC): Economic Policy Institute.

Sanci, R. (2014). *Correlation Among Math Anxiety, Attitudes Toward Math, and Math Achievement in Grade 9 Students: Relationships Across Gender. Masters of Education Thesis.* St. Catherines (ON): Brock University.

Sattler, P. & Peters, J. (2012). *Work-Integrated Learning and Postsecondary Graduates: The Perspective of Ontario Employers.* Toronto, ON: Higher Education Quality Council of Ontario.

Sattler, P. & Peters, J. (2014). *Work-Integrated Learning in Ontario's Postsecondary Sector: The Experience of Ontario Graduates.* Toronto (ON): Higher Education Quality Council of Ontario.

Saxenian, A. (2005). From brain drain to brain circulation: Transnational communities and regional upgrading in India and China. *Studies in Comparative International Development, 40*(2), 35-61.

Saxenian, A. L. (2002). *Brain Circulation: How High-Skill Immigration Makes Everyone Better Off.* Washington (DC): Brookings Institution.

ServCan (Service Canada). (2014a). Skills Development and Training. Retrieved March 2014, from http://www.servicecanada.gc.ca/eng/audiences/employers/skills_training.shtml.

ServCan (Service Canada). (2014b). Youth Employment Strategy. Retrieved July, 2014, from http://www.servicecanada.gc.ca/eng/epb/yi/yep/newprog/yesprograms.shtml.

Sharpe, A. (2002). Productivity Concepts, Trends and Prospects: An Overview. In A. Sharpe, F. St-Hilaire & K. Banting (Eds.), *The Review of Economic Performance and Social Progress: Towards a Social Understanding of Productivity* (Vol. 2). Ottawa (ON): The Institute for Research on Public Policy and the Centre for the Study of Living Standards.

Sharpe, A. (2009). *Best Practices in Labour Market Information: Recommendations for Canada's LMI System.* Ottawa (ON): Centre for the Study of Living Standards.

Shaw, K. (2014). Internationalization in Australia and Canada: Lessons for the Future. *College Quarterly, 17*(1), 1-17.

She, Q. & Wotherspoon, T. (2013). International student mobility and highly skilled migration: A comparative study of Canada, the United States, and the United Kingdom. *SpringerPlus, 2*(132), 1-14.

Simon, B. (2014). *Canada's International Education Strategy: Time for a Fresh Curriculum.* Ottawa (ON): Canadian Council of Chief Executives.

Sjoberg, S. & Schreiner, C. (2005). How do learners in different cultures relate to science and technology? Results and perspectives from the project ROSE (the Relevance of Science Education). *Asia-Pacific Forum on Science Learning and Teaching, 4*(2), 17.

Skuterud, M. (2013). *Recruiting Talent in the Information and Communications Technology (ICT) Sector: What Role for Immigration?* Paper presented at Information and Communications Technology (ICT) Talent Workshop, March 21-22, 2013, University of Ottawa.

Smith, P. & Lam, M. (2013). *2013 Campus Recruitment Report – Recruiters Summary.* Toronto (ON): The Canadian Association of Career Educators & Employers.

Stark, A. (2007). *Which Fields Pay, Which Fields Don't? An Examination of the Returns of University Education in Canada by Detailed Field of Study.* Ottawa (ON): Department of Finance Canada.

StatCan (Statistics Canada). (2010). Participation Rate in Formal Job-Related Training for the Adult Work Force,1 by Sex, Age Group, Educational Attainment and Province, Canada and Provinces, 1997, 2002 and 2008. Table D.7.1. Retrieved May 2014, from http://www.statcan.gc.ca/pub/81-582-x/2010003/tbl/tbld7.1-eng.htm.

StatCan (Statistics Canada). (2011). *Science Statistics: Estimates of Research and Development Expenditures in the Higher Education Sector, 2009-2010. Catalogue no. 88-001-X.* Ottawa (ON): Statistics Canada.

StatCan (Statistics Canada). (2013a). National Household Survey Data Table #99-012-X2011046. Retrieved January 2015, from http://www5.statcan.gc.ca/olc-cel/olc.action?objId=99-012-X2011046&objType=46.

StatCan (Statistics Canada). (2013b). Variant of CIP 2011 - STEM Groupings. Retrieved January 2014, from http://www23.statcan.gc.ca/imdb/p3VD.pl?Function=getVDPage1&TVD=139116&db=imdb&dis=2&adm=8.

StatCan (Statistics Canada). (2013c). National Household Survey Data Table #99-012-X2011039. Retrieved February 2015, from http://www5.statcan.gc.ca/olc-cel/olc.action?objId=99-012-X2011039&objType=46.

StatCan (Statistics Canada). (2013d). *Immigration and Ethnocultural Diversity in Canada. National Household Survey, 2011. Catalogue no. 99-010-X2011001.* Ottawa (ON): Statistics Canada.

StatCan (Statistics Canada). (2013e). *Skills in Canada: First Results from the Programme for the International Assessment of Adult Competencies (PIAAC). Catalogue no. 89-555-X.* Ottawa (ON): Statistics Canada.

StatCan (Statistics Canada). (2013f). Education in Canada: Attainment, Field of Study and Location of Study. Retrieved November 2013, from http://www12.statcan.gc.ca/nhs-enm/2011/as-sa/99-012-x/99-012-x2011001-eng.cfm.

StatCan (Statistics Canada). (2013g). *The Educational Attainment of Aboriginal Peoples in Canada. NHS in Brief. National Household Survey, 2011. Catalogue no. 99-012-X2011003.* Ottawa (ON): Statistics Canada.

StatCan (Statistics Canada). (2013h). *National Household Survey Dictionary, 2011. Catalogue no. 99-000-X2011001.* Ottawa (ON): Statistics Canada.

StatCan (Statistics Canada). (2013i). National Household Survey Data Table #99-012-X2011043. Retrieved October 2013, from http://www5.statcan.gc.ca/olc-cel/olc.action?objId=99-012-X2011043&objType=46.

StatCan (Statistics Canada). (2013j). *Education in Canada: Attainment, Field of Study and Location of Study. National Household Survey 2011. Catalogue no. 99-012-X2011001.* Ottawa (ON): Statistics Canada.

StatCan (Statistics Canada). (2014a). Registered Apprenticeship Registrations, by Age Group. Data from CANSIM Table 477-0053. Retrieved January 2015, from http://www.statcan.gc.ca/tables-tableaux/sum-som/l01/cst01/educ67a-eng.htm.

StatCan (Statistics Canada). (2014b). *Spending on Research and Development in the Higher Education Sector, 2012/2013. Component of Statistics Canada Catalogue no. 11-001-X.* Ottawa, ON: Statistics Canada.

StatCan (Statistics Canada). (2014c). *Custom Tabulations, Based on Postsecondary Student Information System (PSIS), 2000–2011.* Ottawa (ON): Statistics Canada.

StatCan (Statistics Canada). (2014d). CANSIM Table 379-0031. Gross Domestic Product (GDP) at Basic Prices, by North American Industry Classification System (NAICS). Retrieved October 2014, from http://www5.statcan.gc.ca/cansim/a26?id=3790031.

StatCan (Statistics Canada). (2014e). *Education Indicators in Canada: An International Perspective, 2013.* Ottawa (ON): Statistics Canada.

StatCan (Statistics Canada). (2014f). *Industrial Research and Development: Intentions. Catalogue no. 88-202-X.* Ottawa (ON): StatCan.

StatCan (Statistics Canada). (2014g). CANSIM Table 281-0047. Employment and Average Weekly Earnings Including Overtime (SEPH), Seasonally Adjusted, for all Employees by Industries Classified Using the North American Industry Classification System (NAICS), Canada. Retrieved October 2014, from http://www5.statcan.gc.ca/cansim/a26?id=2810047.

StatCan (Statistics Canada). (2014h). CANSIM Table 282-0070. Labour Force Survey Estimates (LFS), Wages of Employees by Type of Work, National Occupational Classification for Statistics (NOC-S), Sex and Age Group. Retrieved March 2015, from http://www5.statcan.gc.ca/cansim/a26?id=2820070.

StatCan (Statistics Canada). (2014i). *Custom Tabulations, Based on Tax Records Linked to the 2006 Census, 2006–2012*. Ottawa (ON): Statistics Canada.

StatCan (Statistics Canada). (2014j). CANSIM Table 477-0055. Certificates Granted to Registered Apprentices and Trade Qualifiers, by Major Trade Group. Retrieved January 2015, from http://www.statcan.gc.ca/tables-tableaux/sum-som/l01/cst01/educ65a-eng.htm.

StatCan (Statistics Canada). (2014k). *Custom Tabulations, Based on Census harmonized microdata files, 1985–2005 or 1986-2006*. Ottawa (ON): Statistics Canada.

StatCan (Statstics Canada). (2014l). CANSIM Table 383-0008. Indexes of Labour Productivity, Unit Labour Cost and Related Variables, Seasonally Adjusted, Quarterly (index, 2007=100). Retrieved February 2015, from http://www5.statcan.gc.ca/cansim/a26?lang=eng&id=3830008.

StatCan (Statistics Canada). (2014m). Job Vacancy Statistics. Retrieved October 2014, from http://www23.statcan.gc.ca/imdb/p2SV.pl?Function=getSurvey&SDDS=5202.

StatCan (Statistics Canada). (2014n). *Custom Tabulations, Based on 2011 National Household Survey (NHS)*. Ottawa (ON): Statistics Canada.

Stuckey, J. & Munroe, D. (2013). *The Need to Make Skills Work: The Cost of Ontario's Skills Gap*. Ottawa (ON): Conference Board of Canada.

Sweetman, A. (2004). *Immigrant Source Country Educational Quality and Canadian Labour Market Outcomes. Catalogue no. 11F0019MIE — no. 234*. Ottawa (ON): Statistics Canada.

Timmermann, A. (2006). *An Evaluation of the World Economic Outlook Forecasts. IMF Working Paper 06/59*. Washington (DC): International Monetary Fund.

Triadafilopoulos, T. (2013). Dismantling White Canada: Race, Rights, and the Origins of the Points System. In T. Triadafilopoulos (Ed.), *Wanted and Welcome? Policies for Highly Skilled Immigrants in Comparative Perspective*. New York (NY): Springer.

Tsupros, N., Kohler, R., & Hallinen, J. (2009). *STEM Education: A Project to Identify the Missing Components*. Pittsburgh (PA): Carnegie Mellon University.

UKCES (U.K. Commission for Employment and Skills). (2011). *The Supply of and Demand for High-Level STEM Skills*. London, England: UKCES.

UNESCO (United Nations Educational, Scientific and Cultural Organization). (2006). *International Standard Classification of Education (ISCED) 1997*. UNESCO Institute for Statistics.

US (Université de Sherbrooke). (2014). Co-op Program at a Glance. Retrieved January 2015, from http://www.usherbrooke.ca/ssp/en/service/co-op-program-at-a-glance/.

UW (University of Waterloo). (2014a). About Co-operative Education. Retrieved September 2014, from https://uwaterloo.ca/co-operative-education/about-co-operative-education.

UW (University of Waterloo). (2014b). Why Co-op. Retrieved September 2014, from https://uwaterloo.ca/co-operative-education/alternative-text-why-co-op

UW (University of Waterloo). (2014c). Co-operative Education: At Work. Retrieved January 2015, from https://uwaterloo.ca/co-operative-education/work

van Huystee, M. (2011). *A Profile of Foreign Students Who Transition to Permanent Resident Status in Atlantic Canada*. Ottawa (ON): Citizenship and Immigration Canada.

Verdine, B., Golinkoff, R., Hirsch-Pasek, K., Newcombe, N., Filipowicz, A., & Chang, A. (2013). Deconstructing building blocks: Preschoolers' spatial assembly performance relates to early mathematical skills. *Child Development*. doi: 10.1111/cdev.12165.

Wensley, K. (2013). *Gender Diversity of Boards of Directors of Canadian ICT Companies*. Ottawa (ON): Information Technology Association of Canada.

WMI (Wallace McCain Institute). (2012). *New Graduate Hiring Survey Results*. Moncton (NB): Wallace McCain Institute.

Wyatt, I. D. (2010). Evaluating the 1996-2006 employment projections. *Monthly Labor Review, 133*(9), 33-69.

Xu, K. & Lin, Z. (2009). *Participation in Workplace Employer-Sponsored Training in Canada: Role of Firm Characteristics and Worker Attributes*. Ottawa (ON): HRSDC-IC-SSHRC Skills Research Initiative.

Yuen, J. (2010). *Job-Education Match and Mismatch: Wage Differentials*. Ottawa (ON): Statistics Canada.

Ziguras, C. (2012). Learning the Hard Way: Lessons From Australia's Decade of Innovation in Student Migration Policy. In D. E. Neubauer & K. Kuroda (Eds.), *Mobility and Migration in Asia Pacific Higher Education* New York (NY): Palgrave MacMillan.

Zucker, L. a. M. D. (2006). *Movement of Star Scientists and Engineers and High-Tech Firm Entry. NBER Working Paper 12172*. Cambridge (MA): National Bureau of Economic Research.

Assessments of the Council of Canadian Academies

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

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