SPOTLIGHT ON SCIENCE LEARNING

THE EVOLUTION OF STEM EDUCATION:
A Review of Recent International and Canadian Policy Recommendations

EXTENDED VERSION
MISSION
Let's Talk Science is a national, charitable organization that motivates and empowers youth to fulfill their potential and prepare for their future careers and roles as citizens. Let's Talk Science supports learning and skill development using science, technology, engineering and mathematics (STEM). Spotlight on Science Learning: The Evolution of STEM Education is the latest research report from Let's Talk Science, made possible by Amgen Canada.

For more information about Let's Talk Science, please visit letstalkscience.ca.

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Spotlight on Science Learning: The Evolution of STEM Education

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It has become commonplace to point to the expanding role being played by technology and the importance of its growing impact on individuals’ and societies’ economic and social prospects. Almost every day, we hear that the future success of advanced industrial countries like Canada hinges on our ability to successfully transition from a 20th century resource extraction or a manufacturing-led economy to an innovation-driven “knowledge economy”.

Within this larger conversation, the role of education and, specifically, the importance of science, technology, engineering and mathematics (STEM) learning is receiving increasing public attention. As a critical driver of this much discussed transition from a 20th to a 21st century (and beyond) economy, STEM learning is being recognized as a priority – not only by governments but by other stakeholders like industry, community organizations, parents and students as well. As the impact of technology on our society continues to grow, the importance of the foundations of STEM learning and associated “competencies” – such as an understanding of scientific methods, numeracy, digital literacy and problem-solving – for individuals’ abilities to participate meaningfully in all spheres of life is becoming increasingly clear.

This paper grapples with some of the key questions facing those who wish to ensure that Canadian students have access to the kind of STEM learning they will need to succeed in the economies and societies of the 21st century – whether it be as innovators working on the cutting edge of technological advancement or as citizens participating fully in the life of their communities. This paper is also a part of the larger Canada 2067 project. Initiated by Let’s Talk Science, Canada 2067 is a unique national initiative designed to shape the future of Canadian STEM learning, with a focus on Kindergarten to Grade 12. Using the perspectives and opinions of Canadians, Canada 2067 will develop an action plan and a national vision for STEM learning aimed at ensuring young Canadians are prepared to compete, thrive and contribute in the rapidly changing world of tomorrow. By gathering insights from international and STEM learning experts, this paper is designed to help support Canada 2067’s goal-setting process. By aligning insights gathered from international and Canadian experts with the six pillars of STEM learning identified by Canada 2067, this paper will help feed these insights into the discussions that this project is working to convene amongst Canadians. In so doing, this paper aims to help ensure that conversations on the current state of Canadian STEM learning incorporate international experiences and best practices.

Acknowledgements
As a part of this paper’s research process, a number of academic experts read earlier drafts and provided extremely helpful comments. For this contribution, the authors would like to thank Dr Julie Bélanger, Dr David Blades, Dr John Murray, Dr Jerine Pegg and Dr Dawn Wiseman. We appreciated you sharing your insights, expertise and time so generously. Your comments have contributed greatly to shaping this paper and the companion, Canada 2067 Learning Roadmap. The authors would also like to thank Dr Bonnie Schmidt who, in addition to commissioning this paper, also provided extremely valuable comments and feedback at several critical moments. Naturally, any errors remain the sole responsibility of the authors.
INTRODUCTION

Societies reflecting on how well-prepared they are to meet present and future challenges will inevitably look to the quality of their education systems. It is through formal education that citizens are expected to acquire many of the skills and qualities they will rely on throughout their adult lives. In the face of such sweeping changes as climate change and the rise of new information and communications technologies (ICT), questions have arisen over whether education systems are adapting as they need to.

In education, few issues have attracted as much public attention as the “STEM” disciplines: science, technology, engineering and mathematics. STEM disciplines are seen as crucial in equipping citizens to meet the challenges of an increasingly knowledge and technologically-intensive society. Societies where students do not receive a sufficiently strong foundation in core subjects such as science and math, and which find themselves without an adequate supply of specialists with advanced scientific skills, are seen to be at a substantial disadvantage as they compete for economic opportunities and engage in collective decision-making (DeCoito 2016, 114-115).

For this reason, both governments and non-governmental organizations are asking how well their STEM education systems are doing and how they might need to evolve in the years to come. Consequently, there is no shortage either of analyses of existing systems’ shortcomings or recommendations for improvements. This report aims to summarize a wide cross-section of these analyses and recommendations by reviewing over thirty reports on STEM education published since 2007.

The reviewed reports are published in English and are focused mainly on STEM education at the primary and secondary levels in developed western countries in Europe, North America and Australia. Reports were selected for inclusion in this analysis largely based on their purpose, namely providing policy advice to governments, their availability and accessibility, and the expertise and knowledge of the education policy literature possessed by one of the authors. Some reports were also included in response to suggestions from reviewers of earlier drafts of this report.

As a group, the reviewed reports were selected so as to give a wide variety of both international and Canadian perspectives on STEM education and its role in society as well as the policies and actions that will be needed as STEM education systems evolve. They include reports supported by a variety of intergovernmental organizations such as the Organization for Economic Cooperation and Development (OECD), organizations focused on particular STEM-intensive industries such as the Information and Communication Technology Council of Canada (ICTC), parliamentary committees, ad hoc expert groups, scientific bodies such as the Royal Society and government education departments.

While primarily produced under the auspices of scientific or STEM-focused organizations, the reports reviewed here also include the perspectives of those concerned with education more generally. The international reports have been included to provide a set of global perspectives on STEM education which will hopefully help situate Canada in a global context and, in particular, in comparison with peer countries. The Canadian reports focus on STEM education in Canada and seek to provide insight into the specific challenges and opportunities which characterize STEM learning in this country. Taken together, these perspectives offer insight into the rapid changes currently underway in education and the growing attention to STEM learning.

Critically, this report does not offer a review of the academic literature on STEM education, a task for which the authors do not possess a comparative advantage vis-à-vis academic researchers. Rather, the aim of this report is to help provide a survey of the discussions that define the current policy landscape. Naturally, this landscape is not disconnected from the academy; in fact, some of the reports reviewed here were written by academics with
a deep knowledge of the academic literature on STEM education. Despite this important overlap, however, the policy landscape is a distinct one and is influenced by some factors whose influence is felt much less keenly in the academy and is missing some of the features that figure prominently in academic discussions. Given its stage-setting purpose, it is our hope that this document, through any omissions it contains, will help to identify for both policymakers and academics where additional bridge-building and collaboration is necessary.

This report has two main parts. The first part considers the nature of the current challenges facing STEM education and the extent to which a consensus is emerging with regards to how STEM education ought to evolve. The focus in the first part is on three overarching themes that emerged from the multiple reports reviewed here, namely the need to:

1. Increase the quantity and quality of graduates from STEM disciplines
2. Broaden knowledge of STEM fields to better equip citizens to meet the demands placed on them in technologically advanced societies
3. Refocus education systems away from the reproduction of set bodies of knowledge and towards the development of critical thinking and problem-solving skills, and other related competencies, among all members of society

These themes closely match the objectives of Let’s Talk Science, which has commissioned this paper. By supporting STEM learning, Let’s Talk Science seeks to motivate and empower youth to fulfill their potential and prepare for their future careers and roles as citizens in a world increasingly shaped by science and technology. As a part of this mission, Let’s Talk Science has launched Canada 2067, a national initiative designed to help shape the future of STEM learning in Canada from Kindergarten to Grade 12. Canada 2067 is intended to convene a Canada-wide discussion and develop a national vision and roadmap for STEM learning in Canada.

The second part of this paper has been designed to support Canada 2067 by feeding the perspectives, expert analysis and recommendations contained in the reviewed reports into this national discussion. Specifically, it aims to summarize the key recommendations from these reports and to examine the extent to which different education systems appear to be moving in the same direction. The findings of this review are organized into six sections that align with the six pillars of the Canada 2067 action plan:

1. How we learn
2. How we teach
3. What we learn
4. Who’s involved
5. Where education leads
6. Cross-cutting issues (esp Equity and Inclusivity)

The report also includes one section focused on an area where the reviewed reports did not yield significant consensus, namely the breadth and depth of STEM education. The report closes by summarizing the consensus around those features perceived as critical to a more successful approach to STEM education.

Finally, the purpose of this paper is to feed international and Canadian policy expertise and perspectives into the conversations about how STEM learning in Canada can continue to evolve. In an attempt to highlight those areas where additional insights are still most needed, each section closes with a set of questions aimed at helping to advance this discussion. The reader is invited to consider these questions and add their responses and perspectives to the larger Canada 2067 dialogue.
IDENTIFYING THE CHALLENGES

This report’s first finding is that internationally there is no shortage of calls to improve STEM education or of policies and initiatives designed to do so. As one report observes, “improving science education has been high on the political agenda... since the end of the 1990s” (Executive Agency 2011, 25).

A second finding, however, is that beneath agreement on the importance of improving STEM education lie different perspectives on exactly how STEM education will need to evolve. Specifically, this discussion is defined by three themes (cf. Fensham 2008, 4-5). The first focuses on the need to increase the quantity and the quality of graduates from STEM disciplines. The second concerns the need to broaden knowledge of STEM to better equip citizens to meet the demands of technologically advanced societies. The third involves the need to refocus education systems away from reproducing set bodies of knowledge and towards developing critical thinking, problem-solving and other critical competencies.

INTEREST IN STEM DISCIPLINES AND CAREERS

The need to increase the quantity and the quality of graduates from STEM disciplines is the most commonly identified challenge in the international studies reviewed for this paper, usually for one or both of two reasons. First, jobs in developed economies increasingly require high levels of STEM skills and economies require a sufficient supply of STEM graduates to drive the innovation they need to remain competitive (Chief Scientist 2014, 7; Executive Agency 2011, 26; ICTC 2016, 6). Second, too few students are choosing to study STEM and these already too-small numbers may even be declining (ACOLA 2013, 40; Osborne and Dillon 2008, 11; European Commission 2015, 17).

Consequently, these reports hold that societies are faced with low supply and high demand for STEM graduates; the “pipeline” from the education system to the labour market is not feeding through graduates at the required rate. “From 2003 to 2013, the number of people working in occupations related to STEM grew by 12%, three times faster than total employment in the EU. Occupations in these fields now account for 7% of all jobs and demand for skills linked to these disciplines is anticipated to increase. Employers in many regions of the EU report difficulties in finding people with the right skills, particularly ICT professionals”. (EU STEM Coalition 2016, 4). As a result, in many countries the supply of scientific professionals “is now falling seriously short” (Fensham 2008, 11; ICSU 2011, 8-9; Chief Scientist 2014, 23). The question, these reports maintain, is how to stimulate more interest among students in STEM subjects and careers.

The situation in Canada appears to be slightly different. As shown in Figure 1, while Canadian post-secondary enrolments in STEM subjects are lower now than they were at their peak in 1999-2000 (as a proportion of all post-secondary enrolments), the proportion of post-secondary students enrolling in STEM subjects has remained fairly steady since the early 1990s at around twenty per cent of all post-secondary enrolments.¹ A number of studies have suggested that, while there may be some skills mismatches in the Canadian labour market, there is little evidence for an across the board shortage of STEM workers (Expert Panel 2015, 32-59; Standing Committee 2012, 11-18).²

¹ Note that in absolute terms, this translates into an increasing number of STEM enrolments.
² It should also be noted, however, that the Expert Panel also found that significant opportunities for improvements in STEM learning existed in Canada, especially in the early years of education. See Expert Panel 2015, 99.
Conversely, other Canadian studies suggest that there may already be a lack of STEM workers or that there soon will be – at least if current graduation rates continue (ICTC 2016, 6 and 8-9; Amgen and LTS 2012, 12).

More abstractly, other studies imply that simply looking at job vacancies in STEM fields is a poor way of gauging the impact of having too few STEM graduates. These studies point to Canada’s falling business dynamism and poor productivity growth and suggesting that more STEM graduates would mean a more innovative economy, more entrepreneurship and more jobs overall.3 Indeed, one report that holds that there is no STEM shortage overall also notes that Canada ranks below other peer jurisdictions in terms of the proportion of its population that holds degrees specifically in science of engineering – indicators that are often linked with innovation.4 Finally, other reports point to the fact that immigrants make up a disproportionate percentage of STEM graduates in Canada and that some types of STEM jobs are disproportionately filled by immigrants, a reality which could mask insufficiencies in Canada’s own STEM “pipeline”.5 This will become an especially important point if, as some studies suggest, Canada may not be able to count on the availability of this highly-skilled immigrant labour for too much longer given increasing international competition for mobile workers in this sector (Standing Committee 2012, 14).

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3 This is especially the case for studies focused on the ICT sector. See Aslunturk et al. 2016, vii.
4 (Expert Panel 2015, 37-38) Canada ranks 17th and 19th out of 28 countries respectively in terms of the proportion of its population that holds (1) at least an undergraduate degree and (2) a doctorate in science or engineering. The Conference Board of Canada includes the number of researchers working in STEM areas as a critical indicator of innovation capacity. See http://www.conferenceboard.ca/hcp/provincial/innovation.aspx
5 The Expert Panel on STEM Skills for the Future (2015, 39) notes that 39 per cent of STEM graduates in Canada are immigrants compared to only 23 per cent in other fields. The Standing Committee report (2012, 18) also noted that some sub-groups of jobs in this sector were particularly vulnerable to off-shoring. If Canada is indeed drawing on a global pool of immigrant labour and if firms have the option of off-shoring if labour costs rise in some STEM sectors such as ICT, this might explain why there has been limited wage growth in this sector, one of the key pieces of evidence that studies like that of the Expert Panel on STEM Skills for the Future rely on for their conclusion that there is not a shortage of STEM workers in Canada.
Opting-out

To the extent that there is a lack of STEM graduates, this insufficiency likely has several causes. One international report describes “a STEM education pipeline with holes, gaps, and weak points, from which students drop out—often at predictable points—due to lack of interest, engagement, help, or financial support” (Kramer et al. 2015, 2). Indeed, many reports identify a loss of interest in STEM between primary or middle school and secondary school; the natural curiosity that younger students have about the natural world fails to translate into a sustained interest in science (Education Council 2015a, 8). One report shows how Canadian students’ interest in science falls over the course of secondary school (See Figure 2). The same report also finds that students’ interest in taking optional science courses peaks at age 15 and then begins to fall, just as compulsory science and mathematics education ends in many provinces and students need to begin selecting these courses as electives (Amgen and LTS 2014, 22).

This loss of interest is at least partially the result of the fact that STEM courses have gained a reputation for being difficult, boring, or otherwise unappealing, prompting many students to opt-out (EU STEM Coalition 2016, 4; President’s Council 2010, 4; Amgen and LTS 2012, 19). STEM also has an “image problem” that makes it seem like the preserve of “geniuses”, “geeks” and “nerds” and appear unwelcoming (Education Council 2015b, 2). Many students seem to self-select out of STEM because “they don’t identify with these stereotypes, lack the self-confidence to challenge themselves with STEM subjects, and are not aware of the many career doorways that STEM can open” (Education Council 2015b, 2). Simply put, many show a “pervasive lack of interest in STEM” and lack of knowledge about STEM-related career opportunities (President’s Council 2010, vi).

This problem of declining interest in STEM is evident in students’ declining enrolment rates in elective science courses after Grade 10 when most provinces’ mandatory science and math requirements end. In British Columbia, for example, in Grade 11, only 44 per cent of students take chemistry, 43 per cent take biology and 36 per cent take physics. By Grade 12, those percentages are down even further to 38 percent, 25 per cent and 16 percent, respectively. Similarly, “in Alberta, in Grade 11 roughly 50 per cent of students take biology, 49 per cent take chemistry and 33 per cent take physics; in Grade 12, the enrolment for the next level in those courses drops to 44 percent, 38 per cent and 21 percent.” (Amgen and LTS 2012, 18).

Inequities

Another problem is that STEM still has a gender imbalance in Canada. While this problem may be less acute than it is in other countries, it is unfortunately still a problem. For instance, data show that 15 year old girls expect to have careers in STEM at a higher rate than boys do (PISA 2015). Critically, however, these expectations tend to cluster in the health-related subjects, a pattern that is replicated at the post-secondary level. Participation in fields including mathematics, computer science, engineering, and physics continue to be quite skewed by gender, especially at the college level, and these are the disciplines usually grouped together as “STEM” in publically available reports. Consequently, while women are increasingly making up the majority of enrolments in fields such as health and life sciences in Canadian universities (AUCC 14-15), they remain underrepresented in STEM enrolments overall as expressed in many reports (see Figure 3).

**Figure 2:** Student responses to questions about science and STEM (Source: Amgen and LTS 2014, 22)

<table>
<thead>
<tr>
<th>Question</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>17</th>
</tr>
</thead>
<tbody>
<tr>
<td>Science is fun</td>
<td>79%</td>
<td>70%</td>
<td>77%</td>
<td>68%</td>
<td>68%</td>
</tr>
<tr>
<td>Science is boring</td>
<td>30%</td>
<td>36%</td>
<td>31%</td>
<td>34%</td>
<td>39%</td>
</tr>
<tr>
<td>I enjoy science courses</td>
<td>74%</td>
<td>70%</td>
<td>72%</td>
<td>68%</td>
<td>63%</td>
</tr>
<tr>
<td>I don’t understand where science leads, so it’s of little interest</td>
<td>29%</td>
<td>28%</td>
<td>31%</td>
<td>28%</td>
<td>36%</td>
</tr>
<tr>
<td>No obstacles would prevent me from studying STEM</td>
<td>30%</td>
<td>20%</td>
<td>23%</td>
<td>19%</td>
<td>19%</td>
</tr>
</tbody>
</table>
Note: STEM includes Physical and life sciences and technologies; mathematics, computer and information sciences and architecture, engineering and related technologies (vis-à-vis other jurisdictions). These “unsatisfactory results in international performance surveys (PISA, TIMSS) are... frequently a motor for new initiatives” (Executive Agency 2011, 27).

Additionally, concerns are also expressed about the types of skills students are acquiring. Some studies observe that STEM education is failing to ensure that STEM graduates are equipped with the full range of skills required by employers. The EU STEM Coalition argues “that graduates from STEM fields lack the problem-solving and communication skills necessary in modern business environments” (The EU STEM Coalition 2016, 4). They argue that STEM education needs to better “equip students with a broad range of competences, including important transversal skills such as creativity, flexibility and an entrepreneurial mindset” (The EU STEM Coalition 2016, 4). Another contends that “the education system in most countries is insufficiently aligned with industry to develop student skills and aspirations that meet employer needs.” Specifically, many STEM graduates “lack basic personal professional skills such as teamwork, communication, and problem solving” (Kramer et al. 2015, 4). Concerns like these are echoed in some Canadian reports (Asliturk et al. 2016, 15-16).

Mixed achievement

Simultaneously, there are also concerns about the declining quality of STEM graduates in some countries. This is often expressed as a concern with a fall in a country’s international test scores – either in absolute terms (a decline in achievement) or in relative terms (as compared to other jurisdictions). These “unsatisfactory results in international performance surveys (PISA, TIMSS) are... frequently a motor for new initiatives” (Executive Agency 2011, 27).

In Canada, Indigenous people make up less than 1 per cent of STEM graduates at the bachelor’s, master’s and doctoral levels – despite representing 3.7 per cent of the adult population (Expert Panel 2015, 123-124). In some countries, STEM graduates “lack basic personal professional skills such as teamwork, communication, and problem solving” (Kramer et al. 2015, 4). Concerns like these are echoed in some Canadian reports (Asliturk et al. 2016, 15-16).

6 It is worth noting that it is very difficult to find disaggregated data on visible minority participation in STEM in Canada. (Hadziristic 2017, 45-46)
7 More encouragingly, Indigenous people make up slightly more than 2 per cent of college graduates in STEM fields.
For comparison – Canada’s recent PISA performance

The Programme for International Student Assessment (PISA) is a triennial survey designed to comparatively evaluate countries’ education systems by testing the skills and knowledge of 15-year-old students in reading, mathematics and science. In 2015, it was administered to 28 million 15 year olds in 72 different countries and economies.

Overall Canadian students’ performance in PISA has been consistently good, though their performance in mathematics relative to other countries has declined in three out of the past four PISA test scores.

Critically, however, these aggregate scores also hide wide variation among provinces with a number of provinces scoring somewhat below the international average (a score of 500) and a few others scoring well above it. This divergence in provincial results is most clearly visible in the 2015 mathematics scores.

<table>
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<tr>
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<tbody>
<tr>
<td>Canada</td>
<td>532</td>
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<td>527</td>
<td>518</td>
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<tr>
<td>NL</td>
<td>517</td>
<td>507</td>
<td>503</td>
<td>490</td>
<td>486</td>
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<tr>
<td>PEI</td>
<td>500</td>
<td>501</td>
<td>487</td>
<td>479</td>
<td>499</td>
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<td>NS</td>
<td>515</td>
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<tr>
<td>NB</td>
<td>512</td>
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<td>502</td>
<td>493</td>
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<tr>
<td>QU</td>
<td>537</td>
<td>540</td>
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<td>ON</td>
<td>530</td>
<td>526</td>
<td>526</td>
<td>514</td>
<td>509</td>
</tr>
<tr>
<td>MB</td>
<td>528</td>
<td>521</td>
<td>501</td>
<td>492</td>
<td>489</td>
</tr>
<tr>
<td>SK</td>
<td>516</td>
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<td>484</td>
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<tr>
<td>AB</td>
<td>549</td>
<td>530</td>
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<td>511</td>
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<tr>
<td>BC</td>
<td>538</td>
<td>523</td>
<td>523</td>
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</table>

Source: OECD PISA Report 2015, Volume 1
The second major theme common across many of the reviewed studies concerns the importance of a scientifically literate citizenry. The starting point here is the observation that “basic science literacy, coupled with scientific ‘ways of knowing’ – namely drawing conclusions based on observation, experiment and analysis – provides citizens with the tools needed for rational debate and sound decision-making” (ICSU 2011, 5).

This is especially true as issues of public policy increasingly possess either a scientific dimension (e.g., climate change) or are directly concerned with the regulation of scientific research, such as medicine or genetics (Amgen and LTS 2012, 5). As the United Kingdom’s Royal Society puts it, “scientific discovery and technological innovation can provide solutions to challenges such as scarcity of food and water, energy supply and security and climate change, but they also raise social and ethical dilemmas. All citizens need the skills and knowledge to be able to make informed decisions about how society handles these issues” (Royal Society 2014, 7). The perceived importance of “science for all” leads several studies to criticize policies that prioritize increasing the quantity and quality of STEM graduates over this more general goal.

Importantly, the need to enhance overall scientific literacy is not necessarily in competition with the first goal of producing more professional scientists; education systems can focus on general and expert training simultaneously. Nevertheless, tension can emerge between deepening STEM education and broadening it, or between making STEM courses more demanding in order to raise the quality of STEM graduates and making STEM courses more widely accessible. In many countries, because of the ways that certain groups such as girls or racialized individuals perceive STEM disciplines as less welcoming, making STEM more accessible often means making STEM courses compulsory in the later stages of secondary education to avoid individuals from these groups opting-out of these courses. Currently, however, science courses at the secondary level are often optional: only six out of 36 European school systems had a compulsory science component on their secondary school leaving exam (Eurydice 2011, 100). In Canada, while all provinces require secondary students to take mandatory science and math courses until the end of grade 10, only Manitoba and Newfoundland and Labrador require a Grade 12 mathematics course while only New Brunswick and Newfoundland and Labrador require a Grade 12 science course (Amgen and LTS 2013, 5).

Ultimately, “getting the balance right between the purposes of enthusing enough students to go on to scientific and technological careers and of giving all students an interest in, and enough knowledge of S&T [science and technology] to appreciate the importance of science and technology in society, is perhaps the major S&T educational issue facing all countries today” (Fensham 2008, 15).
The Programme for the International Assessment of Adult Competencies (PIAAC) is an international assessment of the competencies of adults between the ages of 16 and 65. It was initially administered in 24 countries that represent 70 per cent of the world’s GDP – nine additional countries were added in 2016 – and is organized by the OECD. PIAAC focuses on assessing participants’ skills in literacy, numeracy, and problem solving in technology-rich environments. The OECD sees these skills as foundational for higher order cognitive skills – relevant in all domains of life – and as essential for gaining access to and understanding more specific domains of knowledge. As society becomes more technologically dependent, these skills are likely to become only more important (Parkin 2013, 6).

Canada’s results – which combine results for Canadian-born and educated participants and immigrants who acquired most of their skills elsewhere – on the PIAAC assessments are relatively average. Canada scores exactly the average on literacy, slightly below average for numeracy, and slightly above the average when it comes to problem solving in technology-rich environments. Overall, Canada’s post-secondary education system, especially at the college level, is more inclusive and produces better labour market results than is the average among the countries assessed (Parkin 2013, 32). But these average scores also hide the fact that Canada has an above average clustering of its population at both the high and the low end of the proficiency scales with between one-in-seven and one-in-five Canadians possessing low levels of these skills (Parkin 2013, 17). Thus, while Canada’s primary, secondary, and post-secondary education systems clearly are succeeding in some aspects of their mission to produce an educated citizenry, imparting the fundamental skills essential to success in life more equitably to all Canadians remains a challenge to be overcome.

### For comparison – Canada’s recent PIAAC performance

<table>
<thead>
<tr>
<th>Country</th>
<th>Literacy (mean score)</th>
<th>Country</th>
<th>Numeracy (mean score)</th>
<th>Country</th>
<th>Problem-solving in technology-rich environments (% at level 2 or 3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Japan</td>
<td>296</td>
<td>Sweden</td>
<td>288</td>
<td>Finland</td>
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<tr>
<td>Finland</td>
<td>288</td>
<td>Finland</td>
<td>282</td>
<td>Sweden</td>
<td>42</td>
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<tr>
<td>Netherlands</td>
<td>284</td>
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REFOCUSING EDUCATION SYSTEMS

The third theme takes the need for scientifically literate citizens one step further. It focuses not just on the broadening of scientific knowledge, but also on the more general development of competencies deemed essential in contemporary societies, such as critical thinking, problem solving, communication, collaboration, creativity and innovation (Scott 2015, 4-5) – competencies that are applicable to all domains of life, including work (Amgen and LTS 2012, 5). Indeed, the importance of such “global” or “21st century” competencies has been recognized in recent years by a variety of entities ranging from the Asia Society (Mansilla and Jackson 2011), to the RAND Corporation (Stecher and Hamilton 2014) the Council of Ministers of Education, Canada (CMEC 2017), and the Organization for Economic Cooperation and Development (OECD 2016). In Canada, a number of provincial governments have embraced the concept with British Columbia leading the way by redesigning its curriculum around six “core competencies”: creative thinking, critical thinking, communication, positive personal/cultural identity, personal awareness and responsibility, and social awareness and responsibility.8

Different organizations have identified different sets of traits or skills as important, but significant similarities exist across many of these lists. For example, the Asia Society – one of the original promoters of the global competency – has isolated the following four as critical, namely the ability to:

1. investigate the world
2. recognize perspectives
3. communicate ideas
4. take action

Covering much of the same territory, Council of Ministers of Education, Canada identifies the fostering of the following six global competencies as a critical goal for Canadian education systems and recently agreed to begin working to develop a pan-Canadian strategy for assessing them:

1. critical thinking and problem solving
2. innovation, creativity, and entrepreneurship
3. learning to learn/self-awareness and self-direction
4. collaboration
5. communication
6. global citizenship and sustainability (CMEC 2017)

Much of the impetus for this focus on competencies begins with the profound changes initiated by the arrival of new ICTs which have made civic and economic life more demanding – while simultaneously also opening up new avenues for innovation and engagement. This development has profound implications for the purpose of education. Since factual knowledge can now be easily accessed by anyone, many suggest that education should now become less about transmitting facts from teacher to students and more about teaching them how to evaluate and think critically about information and how to apply it creatively to solving real-world problems. As a European Commission report argues, “success in the 21st century depends upon acquiring key competences rather than simply learning facts”. Accordingly, science education should serve “to develop the competencies for problem-solving and innovation, as well as analytical and critical thinking that are necessary to empower citizens to lead personally fulfilling, socially responsible and professionally-engaged lives” (Expert Group 2015, 14).

From this perspective, the purpose of science education needs to change. It should no longer be seen primarily as a means of leading the brightest students from their first introduction to mathematics and the sciences up a ladder towards a job in a STEM occupation. In other words, the main purpose of STEM learning should not be the production of the next generation of practicing scientists. There is a need to “shift the policy discourse: from ‘increasing interest’ in science to ‘building science capital’” and to “break the ‘science = scientist’ link” (TISME n.d.(b), 4). More specifically, the European Schoolnet network lists problem-solving, innovation, invention, self-reliance, logical thinking and technological literacy as the skills that STEM should help all students develop (European Schoolnet 2011, 7).

The difference between the second and third themes is subtle but important. The second focuses on science literacy – the ability of non-specialist citizens to keep up with and participate in debates informed by scientific understanding. Conversely, the third focuses on reforming all of education so as to shift outcomes away from the imparting of facts and towards the development of competencies.

8 Visit https://curriculum.gov.bc.ca/ for an overview of how British Columbia has redesigned its curriculum.
Importantly, those who contend that the main purpose of STEM education – alongside all other forms of education – should be the fostering of critical thinking and problem-solving competencies are not saying that preparing scientists is an unimportant goal. (In fact, focusing on the teaching of competencies and making STEM learning more compelling might also actually increase the number of professional scientists who emerge.) Instead, those who identify with this third theme simply maintain that improving the production of scientists is not STEM education’s most important objective. Rather, they hold that STEM education should be used, as it is perhaps uniquely capable of doing, to teach much more basic skills and competencies that will be critically important to learners across all domains. Or, as one report put it: “STEM learning is one of the most effective ways to help anyone become more analytical and curious, problem solve, experiment and explore – the very qualities that are needed in the modern workplace” (Amgen and LTS 2012, 8).

The three themes outlined above are not necessarily contradictory. Rather, they should be seen as interrelated parts of a continuum, each with a progressively broader focus as illustrated in Figure 4.

**DISCUSSION QUESTIONS:**

On which of the three challenges should Canada be most focused:

- increasing the number and quality of STEM graduates?
- improving the level of science literacy among all citizens?
- promoting the development of critical thinking and problem solving competencies?

Can each of these three goals be pursued simultaneously, or do education systems need to prioritize among them? To what extent are the three goals complementary, or in competition, with one another?

To what extent is STEM education perceived in Canada as only a gateway to advanced studies and careers in science and not as relevant to all students, regardless of their career aspirations?
RECOMMENDATIONS

Describing the challenges facing STEM education is only the first step; establishing what needs to be done to adapt STEM education and overcome these challenges is also required. Below, we provide a survey of the recommendations from the reviewed reports. These recommendations have been aligned with the six pillars of STEM education identified by Let’s Talk Science in its Canada 2067 initiative.

To be clear, these recommendations are not recommendations that this report is itself advancing. Rather, these recommendations are offered as a curated summary of the policies and actions recommended by the reports under review. It is hoped that by providing this contextual information, this report can help inform a uniquely Canadian discussion of the actions and policies this country’s various education systems can employ as part of their own adaptions to their evolving societies.

It should also be noted that in one area, we did not perceive a strong consensus and have opted instead to provide a description of the difference of opinions that existed.

Interestingly, the different challenges captured by the three themes outlined above are not necessarily associated with distinct recommendations. Frequently, the same recommendations can be advanced regardless of whether the goal is increasing the number of STEM graduates, raising the general level of science literacy, or refocusing education systems on fostering competencies. There are, however, some exceptions: some recommendations apply more to one of these goals than others and, in one notable case, recommendations do conflict.

HOW WE LEARN

A number of recommendations advanced in the reviewed reports concern how learning occurs in STEM disciplines, including course content and expected learning outcomes. These recommendations generally focus on improving pedagogies and often centre on integrating opportunities for experiential and inquiry-based learning into the curriculum.

Experiential learning

One common critique of traditional STEM teaching is that it is too fact-based and uninspiring. This perspective underpins recommendations related to experiential learning, as does the perceived need to get better at developing competencies such as critical thinking and problem-solving. Consequently, many studies conclude that STEM education should include more learning by doing, particularly in the younger years, and that there should be more opportunities to apply science to real-world problems. As Osborne and Dillon note, “this is best achieved through opportunities for extended investigative work, and ‘hands-on’ experimentation and not through a stress on the acquisition of canonical concepts” (2008, 19).

These arguments are echoed in various sources. For example, Australia’s chief scientist calls for “schools to teach STEM as it is practised, in ways that engage students, encourage curiosity and reflection, and link classroom topics to the ‘real-world’” (Chief Scientist 2014, 23). Similarly, a study for the New York Academy of Sciences identified “a strong education system that combines classroom learning with real-world experiences to provide students with both the technical and personal professional skills they need to succeed” as an essential STEM education practice (Kramer et al. 2015, 6). A report prepared for the Information and Communications Technology Council of Canada (ICTC) goes so far as to recommend incorporating “mandatory for-credit experiential learning in all secondary and post secondary educational programs” (Asliturk et al. 2016, viii).
One implication of this emphasis on experiential learning is the need to move outside the classroom. One US report argues that, to create “exciting opportunities for students to have individual or team-oriented experiences with the ideas, discoveries, and emerging knowledge in STEM fields,” government should encourage the expansion of “out-of-class and extended day activities that include contests, laboratory experiments, field trips” and “weekend programs or summer camps”. The report also suggests learners should work “as interns with STEM-oriented companies”, attend “lectures by STEM practitioners, or be mentored or tutored by people in their communities who work in STEM fields” (President’s Council 2010, 87-88).

**Inquiry-based learning**

While STEM disciplines are often seen as inherently nurturing of curiosity, inquiry and problem-solving, some studies conclude that too often, STEM learning is experienced “not as a voyage of discovery, but rather as a dry, fact-based” task (European Schoolnet n.d., 7, 11). Thus, some studies recommend a change in approach involving the adoption of “innovative learning practices” designed to foster “non-disciplinary skills... such as creativity, curiosity and collaboration, as well as entrepreneurial attitudes” (OECD 2012, 207-208).

Osborne and Dillon observe that in STEM education knowledge is too frequently “seen as a commodity to be transmitted”. They argue that school science rarely “transcends the copying of information from the board to the notebook” and suggest that “this limited range of pedagogy” may be “one reason why students disengage with science” (Osborne and Dillon 2008, 22).

In “the most successful countries this traditional approach to teaching and learning is being increasingly replaced with a focus on inquiry-based learning that focuses on making science and mathematics more engaging and practical” and which emphasizes “creativity and critical thinking” (ACOLA 2013, 15). Correspondingly, inquiry- and problem-based learning are “currently widely advocated for science and mathematics teaching as a way to increase motivation and achievement” (Executive Agency 2011, 117).

Similarly, other studies recommend that students tackle “real world problems” through “learning experiences that are hands-on and inquiry-based and support the achievement of deep knowledge” (Education Council 2015a, 11). Other recommendations were aimed at enabling “teachers to innovate and inspire” and to “move away from ‘fact-based’ towards ‘competence-based’ assessment” (European Schoolnet n.d., 20) and toward “assessment regimes that support the commitment to problem solving, inquiry-based approaches, critical thinking and creativity” (ACOLA 2013, 22).

Significantly, these recommendations are relevant to all three challenges outlined in Part 1 of this report. For some, inquiry-based learning is a means to increase the number of STEM graduates by making STEM education more engaging for those already interested in these subjects. For others, it is a way to increase the appeal of STEM education for all students. Still others argue that it is, first and foremost, a better way to ensure that students actually learn and retain — as opposed to memorize for a test and then forget — STEM concepts. Finally, others see inquiry as an essential pathway to developing students’ critical thinking and problem-solving competencies.

**DISCUSSION QUESTIONS:**

To what extent is pedagogy reform in Canada prioritizing inquiry-based and experiential learning? How can this level of prioritization be best assessed or measured?

How can we measure/quantify the extent to which inquiry-based and experiential learning approaches are being implemented?

To what extent is inquiry-based learning embedded in STEM education in Canada? How is inquiry-based learning perceived among educators and education stakeholders?

What needs to change in STEM education in Canada so that it includes more opportunities for experiential learning?
HOW WE TEACH

One point on which almost every study agrees is that effective and inspiring teachers are the most important element of successful STEM education (Education Council 2015a, 8). As a review of European policies observes, “where national strategic frameworks for the promotion of science education exist, they normally include the improvement of science teacher education as one of their objectives” (Executive Agency 2011, 110).

The main challenge identified in this area is not that teachers are poorly educated in general; it is that their education in STEM subjects, and how to teach STEM subjects in particular, is insufficient. Teachers teaching STEM courses without sufficient subject-specific education are described as lacking confidence, more likely to “teach to the textbook” instead of using innovative learning processes, and less likely to inspire a love of the subject (President’s Council 2010, 3). In some instances, teachers may even “be more effective in driving students away from scientific disciplines than attracting them” (ICSU 2011, 16, 9).

The UK’s Royal Society suggests: “all those who teach science and mathematics... should have an understanding of scientific and mathematical concepts to meet the demands of the curriculum. They should be confident in using scientific and mathematical terminology, undertaking practical or mathematical reasoning and modelling work, researching topics in their subjects and helping their students to do likewise” (2014, 86 and 85). For this reason, the “principles of effective initial teacher education” put forward by the Royal Society stipulate that “initial teacher education courses should be focused on developing deep subject-specialist knowledge and conceptual understanding” (2014, 90). Similarly, another study concludes, “the countries strong in STEM...have an unbreakable commitment to disciplinary contents... STEM teachers are expected to be fully qualified in their discipline and to teach in that field and not others” (ACOLA 2013a, 15).

Upon closer examination, this issue divides into several related challenges. One is attracting enough people into teaching who aspire to teach math and science. As the Royal Society notes, “capacity to offer a high-quality science and mathematics education to all young people is hampered by shortages of suitably qualified teachers that have persisted for many years” (2014, 84). Another is ensuring that teaching candidates pursue higher-level courses in math and science as part of their education. A third is ensuring that STEM courses in schools are assigned to teachers with the appropriate education.

Perhaps more important than having advanced education in the STEM subject they are teaching (content knowledge), however, is for a teacher to have advanced education focused on how to teach that subject specifically. This subject-specific “pedagogical content knowledge” is less dependent on a teacher mastering the discipline being taught at an advanced level and more concerned with understanding the common and specific ways in which students tend to learn, and struggle with, these concepts and the best approaches for teaching them.

For example, one report (Guerriero 2017, 108) focused on describing a study published in 2010, which operationalized pedagogical content knowledge in mathematics along three dimensions:

1. a “tasks” dimension focused on teachers’ ability to identify multiple solution paths
2. a “student” dimension focused on teachers’ ability to recognise students’ misconceptions, comprehension difficulties and solution strategies
3. an “instruction” dimension focused on teachers’ knowledge of different representations and explanations of standard mathematics problems

Critically, the study found that it was this pedagogical content knowledge that produced the most positive impact on student achievement, even when compared to the impact of teachers’ content knowledge (Guerriero 2017, 109).
Naturally, while it seems quite likely that there is a non-trivial overlap between advanced education in STEM concepts (content knowledge) and advanced education in how to teach STEM concepts (STEM pedagogical content knowledge), the two do not seem to be the same thing (Guerriero 2017, 108-109). Given that the teaching of pedagogical content knowledge can likely be done in a more targeted way that is quicker, cheaper and more efficient than indiscriminately encouraging or requiring all those who wish to become STEM teachers to spend years earning advanced STEM degrees, this distinction is likely to be good news for those charged with educating and recruiting STEM teachers. This is especially important given that teaching faces strong competition from other, often higher-paying, occupations for individuals who possess the advanced STEM education and skills that come with earning advanced STEM degrees.9

The call for more STEM expertise among teachers is directed not only at those who teach in secondary school, but sometimes at primary school teachers as well. One report argues that “the foundations of STEM competence are laid in early childhood and primary education” (ACOLA 2013, 24). Other reports highlight the importance of every primary school having access to teachers with specialist education in STEM subjects (Royal Society 2014, 97; President’s Council 2010, 103). Though, it is important to emphasize again the finding that specialist education in STEM subjects is not necessarily a reference to an advanced degree in a STEM subject, but could also refer to advanced training in how to teach that particular subject.

One limitation of focusing on improving teacher education is that it does not affect those who have already received their education and will still be teaching for many years to come; for these individuals, professional learning and development is critical. Significantly, this is also how teachers can keep up with developments in scientific and technology-related disciplines – fields where knowledge is expanding rapidly (Education Council 2015a, 8). One study argues that “as in other professions, such as medicine,” teachers must stay current and “should commit to ongoing, career-long professional development.” It then recommends that “subject-specific professional development should be a requirement for all science and mathematics teachers, with recognition and promotion being contingent on ongoing professional development and proven impact on practice” (Royal Society 2014, 95).

Many potential remedies for these challenges have been suggested. These range from recruitment targets for teachers possessing STEM-specific knowledge (President’s Council 2010, 65; Chief Scientist 2014, 23) to greater monetary incentives to encourage would-be teachers to develop these skills and attract more individuals who possess them into teaching (President’s Council 2010, 71; Chief Scientist 2014, 23), to stronger professional development programs (President’s Council 2010, 66).

Overall, improvements to teacher education and professional development are relevant to each of the three goals outlined earlier. Effective and inspiring teachers are needed, regardless of whether one is trying to graduate more STEM students or rethinking the purpose of STEM education. There are specific recommendations relating to teacher education and professional development, however, which are emphasized by those focused on improving overall science literacy and on fostering new competencies. For these individuals, pre-service education and professional development need to be improved not just by improving STEM subject knowledge, but by exposing teachers to new approaches to teaching designed to foster critical thinking and problem-solving skills, such as inquiry-based learning. (ACOLA 2013a, 115; Executive Agency 2011, 128).

Shifting to these new approaches can be difficult.

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Indeed, “research on teacher professional development shows that changing teacher pedagogy cannot be done through short, one-off courses” (Osborne and Dillon 2008, 23). Rather, a more in-depth and ongoing approach is needed, in which all teachers from a school or region are engaged as a collaborative learning community (Executive Agency 2011, 107). Researchers associated with the TISME (Targeted Initiative on Science and Maths Education) project argue that schools need to regularly “schedule time for collaboration, and to ensure that such time is used to foster in-depth interaction between teachers doing subject activities together and discussing strategies” (TISME n.d.(a), 11). They emphasize that “successful implementation of changes in practice depends on coaching support through co-teaching, observation and joint planning and analysis” (TISME n.d.(a), 11). They conclude that professional development initiatives need “to take place in a stable collaborative community over a sustained period of time” (TISME n.d.(a), 11) and need to be given a higher profile “by making them a central and directly evaluated component of accountability for schools” (TISME n.d.(a), 10).

**DISCUSSION QUESTIONS:**

To what extent is STEM education delivered by teachers with specialized education in STEM disciplines in elementary and secondary schools in Canada? Is “out-of-field” teaching an issue in Canadian schools?

To what extent are Faculties of Education distinguishing between content knowledge and pedagogical content knowledge in their teacher education?

Are education faculties in Canada recruiting student teachers with an interest or background in STEM in sufficient numbers?

Are there sufficient opportunities for professional development for STEM teachers in Canada? Are these opportunities provided as sustained processes of collaborative learning within and across schools?

**THE BREADTH AND DEPTH OF STEM EDUCATION**

As mentioned earlier, the question of whether the purpose of STEM education is to guarantee society an ongoing supply of top quality STEM graduates or to ensure that all of society has a broad level of basic scientific literacy and competencies is one area where our research found disagreement. This is notable because, unlike in other areas discussed here, it tends to produce some tension between the different recommendations offered by the various reports being reviewed.

Those concerned mostly with the quantity and quality of STEM graduates tend to focus on students already interested in STEM, and recommend including more advanced courses, or the introduction of STEM-specific streams, to ensure these students are sufficiently engaged and challenged. For example, one report recommends creating “STEM Early College Academies” aimed at helping “students aspire to and achieve STEM leadership and accelerated careers.” These Academies would provide “an enhanced environment for comprehensive and coordinated STEM secondary education” and would “prepare them for success in rigorous undergraduate STEM degree programs” (Governor’s Task Force 2015, 28-29).

Alternatively, those who are more focused on fostering scientific literacy and competencies can view a focus on advanced students as counter-productive. In fact, one study concluding that “the positioning of STEM disciplines as the premier device for identifying innate talent, and assigning privileged pathways to the bearers of talent, corrupts the potential for STEM for all. STEM imagined and practiced solely as the high ability/high performance/high ambition track is the death of universal science literacy” (ACOLA 2013, 73).
DISCUSSION QUESTIONS:

How should Canada define the balance between depth and breadth? Does STEM education across Canada strike the right balance?

How can curriculum reform offer greater challenges to high-achieving students while at the same time promoting science literacy and critical thinking competencies among all students? Which of these two goals requires more attention in Canada and why?

Should the curriculum offered in Canadian schools provide fewer course selection choices to senior high school students in order to minimize opportunities for opting-out of STEM and to ensure that all high school graduates have a strong foundation in STEM-related disciplines?

Is there too much concern in Canadian schools with developing high achieving STEM students and not enough focus on developing methods to meet the need of other students? How do we address the issue?

The TISME researchers concur. They recommend making the UK curriculum less narrow by replacing the current system of A-levels with a “baccalaureate system in which the norm would be for students to study a broader range of subjects” (TISME n.d.(a), 4). The problem with the A-level system is that it tends to restrict STEM courses to those few students who want to embrace STEM as their future. A baccalaureate system would offer less specialization and “a broader (more inclusive) range of post-16 STEM options… open to students with a wide range of attainment” (TISME n.d.(a), 4). Baccalaureate advocates argue that “not only would broader post-16 science options enable and encourage more students to study science post-16. They would also lead to improved levels of scientific literacy across each year group… and help to shift policy discourse away from focusing narrowly on the needs of the science “pipeline”… towards a more prominent valuing of scientific literacy among the general public” (TISME n.d.(a), 4).

Approaches aimed at keeping all students engaged in STEM imply placing limits on student choice in terms of course selection in the final years of secondary school. Several studies observe that making STEM subjects optional too early can reinforce social inequities: students from more advantaged backgrounds tend to perform better and are more likely to select into STEM, while others tend to self-select out for many of the reasons already discussed. Thus, STEM education functions as a means of “social selection” and as an “elite track for university entry and social advantage” (ACOLA 2013, 76).

Some tension may be inevitable. One study describes two strategies which it identifies as inherently contradictory: “STEM tracking”, involving “a firm and possibly early bifurcation between STEM and non-STEM tracks” designed to “strengthen high achievement STEM,” and “an integrated secondary curriculum” constituted by “a less specialised and more integrated upper secondary curriculum… in which all students would pursue mathematics, science and humanities,” designed to strengthen “science for all” (ACOLA 2013, 74).

Not everyone accepts this tension as unavoidable. Australia’s education ministers, for instance, recently endorsed a STEM education strategy that includes both goals. Goal 1 focuses on ensuring that “all students finish school with strong foundational knowledge in STEM and related skills,” while Goal 2 seeks to ensure “that students are inspired to take on more challenging STEM subjects”. Nonetheless, the strategy does not explain how these goals will be reconciled beyond identifying Goal 1 as primary and 2 as supplemental.

Another way to understand this tension between depth and breadth is as between policies aimed at higher and lower achieving students. Many of the so-called “pipeline” strategies are concerned with ensuring that the best students are steered into and prepared for STEM careers. By contrast, one study found that “no European country has implemented a specific policy to address the needs of low achievers in science subjects” (Executive Agency 2011, 127). Thus, another diverging recommendation is to balance the development of more advanced courses with improvements – such as new curricula and resources – aimed at lower achieving students (TISME n.d.(a), 12-13).
WHAT WE LEARN

Many recommendations advanced in the reviewed reports concern what is taught in STEM disciplines, including course content and expected learning outcomes. These recommendations generally focus on improving curricula and, more specifically, on integrating education on ICTs into the curriculum and on increasing its interdisciplinarity.

Digital literacy and Information and Communications Technology (ICT)

In its Skills Outlook 2013 the Organization for Economic Cooperation and Development (OECD) released the results of the Programme for the International Assessment of Adult Competencies (PIAAC). This study found that computer literacy would likely soon join literacy and numeracy as an essential basic skill, noting that “familiarity with and use of ICTs has become almost a prerequisite for accessing basic public services and exercising the rights and duties of citizenship” (OECD 2013, 46).

Adding digital literacy and education on how to use ICTs to the curriculum was similarly identified as essential by many of the reviewed reports. For instance, the European Schoolnet advocates that STEM education should, inter alia, promote “technological literacy” to ensure that students can “understand and explain the nature of technology, develop the skills needed, and apply technology appropriately” (European Schoolnet n.d., 7). Recommendations relating to the teaching of computing skills are also usually driven by the desire to foster problem-solving skills more generally (Education Council 2015b, 4).

For example, Australia’s education ministers identified “the development of higher order computational, problem solving and creative thinking skills through the rollout of the Australian curriculum on technologies, including a deep engagement with coding” as a priority (Education Council 2015a, 8). Similarly, a US report urges school districts to introduce coding into curricula for all K-12 grades “to enable all students to gain 21st century science and math literacy skills which include problem-solving and logical thinking skills” (Governor’s Task Force 2015, 18). But while calls to teach coding in primary school and to “incorporate computer science into the K-12 curriculum” (Asliturk et al. 2016, viii) seem to offer straightforward solutions, others caution that too singular a focus on “coding classes” can obscure “the wider spectrum of digital literacy and STEM training” (Hadziristic 2017, 8) required for “a strong knowledge economy and innovation sector” (Hadziristic 2017, 8). However this debate is resolved, a lack of teachers who are themselves sufficiently digitally literate to teach students remains an important challenge across Canada (Hadziristic 2017, 31).

Some discussions go further and focus on how ICTs can underpin new approaches to teaching and assessment and new forms of interaction between and among educators and students (Royal Society 2014, 51). One US report notes, for instance, that “information and computation technology can be a powerful driving force for innovation in education, by improving the quality of instructional materials available to teachers and students, aiding in the development of high-quality assessments that capture student learning, and accelerating the collection and use of data to provide rich feedback to students, teachers, and schools” (President’s Council 2010, 12).

Examples of such innovations range from the “flipped classroom” concept – where students watch video lectures as homework to learn concepts thereby freeing-up classroom time for teachers to work directly with individual students struggling to understand a concept – to new individualized forms of computer adaptive testing (CAT), to the use of “gamefication” techniques to better motivate students and render learning more enjoyable. Moreover, by opening up opportunities to analyze vast new quantities of individualized data that can shed light on how a student is learning and where they are having trouble, new assessment techniques can help educators tailor their teaching to those students at an individual level.
A UNESCO report notes educators’ difficulties in keeping up with the changes created by new ICTs (Fensham 2008, 31). The study’s author argues that “in revising the curriculum for science and technology, an explicit emphasis will be needed on those aspects of these areas that these ICT tools now make possible” (Fensham 2008, 33). The advantages of doing so are many, including the possibility of improved pedagogies, the ability to bring STEM education into greater sync with science and technology practice, and potential for ICT to help students develop reasoning and critical analytical skills (Fensham 2008, 33).

**Interdisciplinary learning**

Strengthening the connection between STEM and non-STEM disciplines was also often identified as important. For some, this means replacing “STEM” with “STEAM” – referring to science, technology, engineering, arts and mathematics. STEAM is particularly (though not exclusively) associated with South Korea where it has emerged as “a decisive curriculum response to a perception that students were not finding the STEM curriculum engaging, and that the curriculum was not addressing the objective of creativity” (ACOLA 2013, 108; see also 102).

Many believe this strategy should be emulated (ACOLA 2013, 22). The European Commission’s expert group advocates “incorporating the knowledge and the methods and approaches of more than one disciplinary context to enable new ways of thinking and identifying solutions to problems that fall outside the boundaries of just one discipline” (Expert Group 2015, 15). The group recommends focusing science education “on competences with an emphasis on learning through science and shifting from STEM to STEAM by linking science with other subjects and disciplines.” (Expert Group 2015, 9).

The emphasis on fostering creativity in STEM education is fully consistent with the move away from traditional rote learning towards an inquiry-based approach (cf. ACOLA 2013, 15). It is also advocated, however, as a means of making STEM education more engaging and of facilitating “development of sought-after skills for employment, including teamwork, collaboration and the ability to ‘make connections’ between different areas of knowledge” (Royal Society 2014, 50 and 49).

One good example of how this can all be done comes from Finland’s move towards “phenomenon-based teaching”. As part of an education reform undertaken in 2016, all Finnish middle-schools have been required to institute at least one extended period of interdisciplinary phenomenon-based learning each school year. During these periods, usually lasting a week or two, students work on a project that is designed to integrate learning from all of the students’ traditional subject areas. In so doing, the students are meant to learn in a more holistic way that better resembles how students will need to apply their knowledge and skills in the real world.10

**DISCUSSION QUESTIONS:**

To what extent is curriculum reform in Canada prioritizing interdisciplinary learning and education focused on ICTs?

How successful has STEM education been at taking advantage of the teaching and learning possibilities offered by new ICTs?

Are interdisciplinary approaches welcomed or resisted by STEM educators in Canada?

What are the key elements of a successful interdisciplinary approach to education?

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WHERE EDUCATION LEADS

A number of studies argue that interest in STEM education has waned because students lack awareness of its relevance to employment opportunities. Too many students mistakenly assume that science education is only relevant to those wishing to pursue a career “as a scientist, science teacher or doctor” (TISME n.d.(a), 6). Indeed, students often hold “stereotypical and narrow views about science careers” and possess “no information at all about what it means to be a scientist or an engineer” (Executive Agency 2011, 48). Consequently, students don’t understand the transferability of STEM skills or the range of careers that STEM qualifications enable (Norwegian Ministry n.d., 22). Canadian surveys support this assessment, finding that as students move through secondary education an increasing number “fail to see how [STEM] education will be relevant at all to any future job” (Amgen and LTS 2012, 5).

This is especially a problem for students from families with limited connections to science. In some contexts, this problem is exacerbated for girls, many of whom, for example, do not “pursue physics because of influence from family members and a lack of knowledge and understanding of... the career options that studying it can lead to” (Royal Society 2014, 31; Norwegian Ministry n.d., 22). Conversely, and not nearly as prominent in public discussions, there is also growing evidence that a significant gender imbalance in the other direction, that is boys and men being significantly underrepresented in some STEM fields – such as health and life sciences – is brewing in Canada (AUCC 2011, 14-15).

Better information about how STEM disciplines connect to a wider range of careers is seen as crucial to keeping students engaged with STEM education. As one European study notes, “there is, therefore, a need for both science-related and gender-sensitive educational and vocational guidance to increase motivation and encourage the interest of both girls and boys in science subjects and careers” (Executive Agency 2011, 49).

In this vein, the Chief Scientist of Australia has recommended that government provide “career advice for students that explains the value of study in the core STEM disciplines and the pathways to work it opens, not only in STEM-related fields” (Chief Scientist 2014, 23). Australia’s education ministers have advised school leaders to expose students “to a wide range of career options and information early to help increase STEM aspirations and engagement, ideally in primary school and continuing throughout high school, and involving parents and school communities where possible” (Education Council 2015a, 11). The Royal Society offers similar recommendations and also highlights the importance of students’ exposure to “real world STEM role models” (Royal Society 2014, 10). Another report recommends simply that “science, technology and mathematics lessons should feature ‘embedded’ careers education to a far greater extent than at present” (TISME n.d.(a), 6).

In some countries, the more academic STEM learning pathways centred on a university education overshadow the more vocational pathways that run through colleges and polytechnic institutions. In many European countries, such as Germany, Finland, the Netherlands and Sweden, tertiary level vocational educational institutions such as the celebrated fachhocschulen have helped to avoid the obscuring of such pathways (ACOLA 2013, 78). But in many other countries, too many students and parents seem to see a university education as the critical pathway to forms of employment that require STEM skills. In advanced economies especially, however, STEM skills are becoming increasingly essential for many vocational occupations previously not perceived as requiring them (Education Council 2015b, 2). Ensuring that students and parents are aware of the vital role played by STEM skills in these areas, as well as the STEM opportunities available in more vocational or technical occupations, represents an important challenge for many education systems.

DISCUSSION QUESTIONS:

How and when do students acquire career guidance during schooling?

What elements of career education should be improved to reflect the changing nature of work?

Is careers education sufficiently embedded in the STEM curriculum in Canada?

How do students learn about the diversity of post-secondary pathways (college, university, polytechnics, apprenticeship etc.) and their connection to STEM?
WHO’S INVOLVED

External partners can help educators link in-class lessons to the “real world” in which science is applied, be it the research laboratory, the workplace, or the natural environment. They can connect students directly with practicing scientists and demonstrate the relevance of science to careers and civic life. And they can facilitate the innovative teaching and learning experiences needed to inspire students to engage with science education and broaden their range of competencies. But, as the number of entities involved in STEM education increases, so too does the importance of competent leadership within the sector as well as effective collaboration and coordination between partners. In particular, several studies note that while there are many initiatives aimed at addressing the challenges facing STEM education, what is often needed is more leadership to better coordinate different initiatives within a single framework, ensure they are adequately resourced and make sure that successful initiatives are scaled-up. (Executive Agency 2011, 9 and 56; President’s Council 2010, 11).

The European Commission’s expert group captures this perspective well arguing that collaboration between “educational providers, enterprise and civil society should be enhanced to ensure relevant and meaningful engagement of all societal actors with science and increase uptake of science studies and science-based careers”. It also recommends promoting “partnerships between teachers, students, researchers, innovators, professionals in enterprise and other stakeholders in science-related fields” (Expert Group 2015, 10, 23). These partnerships can be built between educators and a variety of external entities. A number of studies also laud several countries’ “national STEM policy frameworks which provide targets, objectives, metrics, approaches, coordination and collaboration across institutions and initiatives” (ACOLA 2013b, 1) and which help to bring coherence to these countries’ varied initiatives.

Partnerships with the private sector and employers

Partnerships with employers, especially those that employ graduates with STEM skills, are generally recommended for three main reasons. First, they can provide students with “access to role models and to career information which might stimulate a desire to work in the field” (Executive Agency 2011, 32). Moreover, by “showing the relevance of science in everyday life, learning experiences within a partnership might encourage pupils to continue their career in science branches at secondary level and later on in higher education” (Executive Agency 2011, 32). Second, employers are seen as ideally placed to provide information about the relevance of STEM education to a wide range of occupations. As the Royal Society notes, “if schools are to offer excellent careers advice and work experience they need to have a stronger relationship with employers. This must be a sustained relationship, where both sides influence each other and the link has an influence on how the school is run, the curriculum and its ethos” (Royal Society 2014, 60). Third, collaboration can create experiential learning opportunities for students. This exposure to “real life” science and STEM-related jobs has the potential to engage students more deeply in STEM education and inspire them to pursue STEM-related studies and careers (Norwegian Ministry n.d., 31). As Australia’s Chief Scientist puts it, “linking teachers and students to STEM professionals in real workplaces provides inspiration and motivation and strengthens knowledge of contemporary practices as well as helping to secure the pipeline of future STEM professionals” (Chief Scientist 2014, 10). Similarly, Canada’s Information and Communication Technology Council, an ICT industry association, similarly recommend that educators, “industry and government should strategically enhance their work together to build education programs that better align with industry needs and improve student entrepreneurial and employment outcomes” (Asliturk et al. 2016, 42).
Partnerships with community organizations and public agencies

Importantly, the private sector is not the only potential partner. The learning opportunities described above can also be delivered in collaboration with a variety of other organizations including universities and colleges, museums, botanic gardens, zoos, environmental education centres, observatories, science centres and parks, and media outlets (Chief Scientist 2014, 12). Such partnerships with community organizations not only serve to increase the variety of opportunities, they also raise the profile of STEM knowledge and careers in other – often public sector – contexts, which can help build a more supportive environment for STEM education and stimulate students’ interest.

Community organizations are often seen as particularly effective in delivering “informal science learning” or “enrichment activities” (see, for instance, Lloyd et al. 2012; ACOLA, 2013a, 150 ff.). Informal learning “refers to activities that take place outside of the formal education system and that seek to raise awareness of, interest in and engagement with science and the... [STEM] subjects” (Lloyd et al. 2012, 11). Because they tend to complement formal school-based learning, they often offer more sustained support to educators than do interactions with employers. The European Schoolnet argues for an approach that “goes far beyond the scope of traditional public-private partnerships, which typically engaged primarily government actors with private partners” whose involvement is usually limited to financial sponsorship (European Schoolnet n.d., 10). Indeed, “a single encounter with a science-based activity post-[age]14 is unlikely to have a significant impact. What is required is a continuum of educational experiences of science from an early age” (Osborne and Dillon 2008, 19).

For some, collaboration with community organizations can be beneficial for other reasons. As Falk et al. argue, “there is already extensive evidence that individuals are engaged and develop much of their understanding and knowledge outside of the classroom.” Thus, “while school does matter in helping students develop formalised and general principles, it is the experiences outside the classroom that are essential to give meaning, relevance and context to the ideas that schools offer” (Falk et al. 2012, 3 and 11).

Partnerships between schools and science-related organizations with a public education mandate, such as science centres, are also possible and are, in fact, common across Europe. These organizations can also provide special activities that “can make a significant difference to how young people view and understand science as well as to how motivated they are to study and work in this field” (Executive Agency 2011, 9, 43). For example, in 2016, the European Space Agency estimates that through its programming it was able to engage almost a million primary and secondary students and over 50,000 teachers in 13 countries through education and outreach activities ranging from robotics and “CanSat” satellite building competitions for students, to space-focused professional development activities for teachers (ESAC 2017, 30).

Across Canada there is a significant and growing network of community-based organizations that engage youth and educators in diverse STEM-based learning experiences.

Leadership, coordination and collaboration

“Ensuring strong and strategic” leadership is a common recommendation in these studies (President’s Council 2010, 10 and 13). Often in the form of national institutes, such bodies are seen as creating “a strong mechanism to ensure leadership and coordination for STEM programs within the [education] department”. Independent commissions capable of monitoring and promoting progress are also seen as valuable (President’s Council 2010, 34, 36). The belief is that “national coordination will make a significant contribution to the enhancement of STEM education... as it has been shown to do in many other countries” (ACOLA 2014b, 6).

Other studies have also advocated the development of approaches that emphasize horizontal collaboration among stakeholders. The recommendations are based on the idea that improving STEM education requires
engaging not only governments, education systems, schools and teachers, but also parents, community organizations, the science and technology research community, and businesses. One argues that progress “depends not only on educators and schools,” but also requires “a larger, more comprehensive solution.” Building such a cooperative solution requires “a thriving STEM culture that infuses the entire population with an understanding of the importance and opportunity that lies within STEM” (Kramer et al. 2015, 6). In other words, for a STEM education system to be strong, it needs to be embedded within a larger STEM ecosystem that is healthy and highly interconnected.

Parents

While a qualitatively different relationship from the sorts of partnerships described in the earlier sub-sections, the involvement of parents is an essential – and often the definitive – factor influencing a student’s education and career path. Nonetheless, one of the reviewed studies found that Canadian parents are often poorly informed about their children’s STEM education and tend to discuss STEM education and careers fairly rarely – even though they have enormous influence over the children’s educational choices.

More specifically, this study found that 31 and 59 per cent of parents believe that science and math respectively are mandatory subjects through to the end of high school when in most cases they are not (Amgen and LTS 2015, 15). Additionally, despite a strong majority saying that they believe that science is critical to their children’s futures and careers (Amgen and LTS 2015, 12), only 28 per cent of parents say that they often discuss the value of taking optional science courses with their children, while 29 per cent say that they rarely or never raise the subject (Amgen and LTS 2015, 14). This is important because, as another report found, 76 per cent of children say that their parents have the greatest influence on their educational direction.

Parents’ influence can be transformative, which is why it is so important to ensure that parents are a central part of the community that supports students’ STEM education. Parents who do not themselves have a full understanding of STEM and the career doors that it can open for their children – or the doors that a lack of STEM education can close - are less able to provide children with the encouragement they might need to pursue it (Education Council 2015b, 2). Without this encouragement, many students many not take the steps in secondary school, like taking optional science or math courses, needed to be able to pursue STEM subjects later on in their education.

DISCUSSION QUESTIONS:

How successful have Canadian teachers and schools been at building partnerships with entities outside the formal K-12 education systems? What factors have contributed to this situation?

How effectively have parents been involved in their children’s STEM education?

Are businesses aware of the possible roles they can play in enhancing STEM learning opportunities in elementary and secondary education?

What key strategies have been used successfully by community organizations to partner with schools to develop enriched STEM learning opportunities?

How could STEM education initiatives at the provincial/territorial level in Canada become better coordinated or integrated into an overall strategy or framework?

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11 In fact, as discussed earlier, only Manitoba and Newfoundland and Labrador require a Grade 12 mathematics course while only New Brunswick and Newfoundland and Labrador require a Grade 12 science course (Amgen and LTS 2013, 5).
12 Teachers come in second place with only 24 per cent. See Amgen and LTS 2014, 6.
CROSS-CUTTING RECOMMENDATIONS

The studies reviewed here also advance a number of additional recommendations that are not fully captured by the preceding sections of this report. Two of these are of particular importance, because of how they are interwoven into the others instead of standing alone as discrete recommendations.

The early years of education

The first of these cross-cutting recommendations is the need to pay particular attention to the early years of education, prior to when students begin specialized study of the separate STEM disciplines such as biology, chemistry and physics. Many studies maintain that young students are naturally drawn to science because of their inherent curiosity about the natural world, but that too little is done to nurture and sustain this early interest. Osborne and Dillon lament that “somehow we have managed to transform a school subject which engages nearly all young people in primary schools... into one which the majority find alienating by the time they leave school” (2008, 27). In response, Australia’s STEM education strategy includes “supporting a focus on STEM in early childhood education to build on early curiosity for science and technology” and “recognising the primary and middle years as critical periods when students begin to cement their aspirations for, and confidence in, STEM” (Education Council 2015a, 8).

The need to focus on the early years of education is best understood as a dimension of all the other recommendations discussed above. Teacher education and professional development should be concerned with the specific requirements of science and math education from early childhood onwards; curriculum reform needs to include making STEM engaging for students at every level of education; information about the relevance of STEM to careers needs to be provided at a young age; and so on. Thus every reform should be undertaken in part with an eye to addressing the situation of younger students.

Equity in STEM education

The second cross-cutting recommendation concerns the need to address inequity. There are three particular inequities in terms of participation and achievement in STEM that draw consistent attention. The most commonly mentioned is between girls and boys: girls are typically described as losing interest in STEM as their education progresses such that girls and women are significantly underrepresented in STEM studies in high school, college and university and in STEM careers. The second is socio-economic inequity: students from lower-income backgrounds do not receive the encouragement and support that they need to succeed in STEM. Consequently, STEM education ends up perpetuating social inequality by disproportionately conferring the advantages that flow from STEM qualifications on students from advantaged backgrounds. The third concerns ethnicity or race: students from minority backgrounds, including Indigenous students in some countries, are underrepresented in STEM-related studies and employment, often as a result of stereotypes which perpetuate the view that they are uninterested in or unlikely to succeed in STEM.

As was mentioned earlier, in Canada, Indigenous students in particular face significant cultural obstacles and barriers to participation in STEM. As one study notes “most Aboriginal students’ experience science education ‘as an attempt at assimilation into a foreign culture’” (Canadian Council of Learning 2007, 2). It should come as no surprise then that Indigenous students have much lower levels of achievement than the average for Canadian students (Canadian Council of Learning 2007, 6-7).

Many countries that are strong in STEM education “have developed innovative policies to lift STEM participation among formerly excluded groups” (ACOLA 2013a, 15). In one of its reports, the Canadian Council of Learning pointed to two main lessons for how to help improve
results for Indigenous students. First, set high standards, but do so in contexts that are designed to enable some flexibility for how and when these standards are met. Second, ensure that curricula are culturally relevant (Canadian Council of Learning 2007, 8).

Some examples of approaches that incorporate these lessons which have been cited as producing positive results – such as increased uptake of post-compulsory science courses by Indigenous students – are the culturally responsive strategies that have been developed in Saskatchewan. This culturally responsive teaching is described as possessing the following six characteristics:

- Specific attention to the learning needs of Indigenous students
- Integrating Indigenous knowledge into science classes
- Culturally appropriate teaching strategies
- Assessment involving culturally valid ways of students communicating what they know
- Culture-based patterns of classroom inter-personal communication
- A learning environment experienced by students that is framed around these five areas. (ACOLA 2013, 146)

Other strategies and recommendations aimed at increasing participation and success by groups currently underrepresented in STEM also focus on identifying the obstacles currently blocking participation by the specific group in question. One study argues that in order to reach a point where women and girls participate equally in all fields of STEM, more work still needs to be done to identify all the “obvious, and not so obvious, ways in which girls are still discriminated against with respect to access to science and technology education. Changes will be needed in structural conditions that reinforce this lack of gender equity, and professional development must continue to make curriculum designers, and teachers aware of how gender inequity can be reduced” (Fensham 2008, 19).

DISCUSSION QUESTIONS:

Is there a sufficient focus in Canada on STEM education in the early years of school? What is being done to ensure that students’ early interest in STEM does not dissipate as they progress through school?

How can educators in Canada address inequities in STEM education?

Is gender disparity in STEM a problem in Canada? If so, how is it being addressed?

How is STEM education evolving to address the specific needs of Indigenous students and to incorporate Indigenous perspectives into STEM teaching and learning?
CONCLUSION

Each of the studies reviewed here was designed to respond to the circumstances of a particular country or region and its education system. What is striking, then, is not their differences but their many similarities. Naturally, the shared conviction that STEM education is a crucial factor in preparing employees and citizens to navigate a more knowledge and technologically-intensive world is unsurprising. What is noteworthy are the recurring themes relating to the key challenges, and the similarity of the recommendations advanced. This makes it possible to identify areas of consensus regarding several key features of a more successful approach to STEM education.

1. The strongest consensus relates to the importance of teacher education and professional development. The concern is not that teachers are poorly educated, but that too many of those who teach math and science are not specifically educated in those disciplines and in the best ways to teach them. There is agreement that, to be successful, STEM education needs to be delivered by STEM specialists, even in the early years of education. There is also agreement that STEM teachers need to be provided with professional learning and development opportunities, and that these opportunities must be sustained and activate collaborative learning communities among teachers within and among schools.

2. There is also agreement that STEM education needs to move away from emphasizing the transmission of set bodies of disciplinary knowledge and towards more multi-disciplinary inquiry-based approaches. Students’ experience of science education should better resemble the processes of open-ended problem-solving and discovery that characterizes scientific practice. To that end, students should be provided with more inquiry-based and “real world” experiential learning opportunities.

3. Given its expanding importance in our economy and in society more generally, an increased focus on digital literacy and how to use ICT in curricula is also widely seen as critical. While certainly no panacea, many of the reviewed reports also emphasized the teaching and learning possibilities that increased engagement with these technologies offer. Similarly, greater integration of interdisciplinarity into the curriculum was also seen as a good way to achieve the increasingly important educational goals of enhancing the development of students’ creativity and problem-solving competencies.

4. Concern was voiced in many studies over the lack of awareness among students and parents of the relevance of STEM to employment opportunities. Successful STEM education systems are those that embed regular career education in the curriculum at all levels so as to improve students’ – and parents’ – understandings of the connection of STEM disciplines to a wide range of careers.

5. The successful delivery of STEM education is seen as requiring collaboration with a variety of partners, including the private sector, community organizations and especially parents. Collaboration between stakeholders has the potential to demonstrate to students the relevance of STEM education, inspire and support them in their pursuit of STEM-related studies and careers even when the subjects may seem difficult, and better align learning outcomes with the needs of the workplace. Partnerships can also be developed with community organizations, and with public agencies. Such partnerships can serve to expand the number and type of STEM learning opportunities and raise the profile of STEM knowledge and careers for students. By informing parents about the importance of STEM and how their kids are learning, these partnerships can also help to activate this key influence on students and their decision-making. Studies also noted the need
for stronger leadership and coordination of these efforts, and improved horizontal collaboration among stakeholders, to ensure that these efforts receive adequate resources, that successful efforts are scaled-up, and that these efforts also help to strengthen the wider STEM culture within society.

6. Finally, there are also two cross-cutting recommendations best understood as woven through all of the issue-specific recommendations. The first focuses on paying particular attention to STEM learning in the early years of education, prior to when students begin specialized study of the separate STEM disciplines. The second is to address inequities in terms of participation and achievement in STEM education, including inequities between boys and girls, students from different socio-economic backgrounds, and Indigenous students and students from minority groups and non-minority groups.

One area where there is less consensus, however, concerns whether the improvement of STEM education should prioritize breadth or depth. For some, the need to increase the quantity and quality of STEM graduates pushes towards strengthening learning opportunities targeted at those already interested in STEM subjects to ensure that they are sufficiently engaged and challenged. For others, this “pipeline” approach is counterproductive, as it reinforces the impression that STEM is only for the gifted elite. From this perspective, it is better to focus on “STEM for all” by making STEM education more accessible. In an ideal world, both strategies can be pursued simultaneously without either interfering with the other. In practice, however, difficult choices must often be made in terms of curriculum (for example, whether to make STEM courses optional or compulsory) and the allocation of resources.

This tension returns us to the question of the precise challenge being tackled. The recommendations advanced in order to improve STEM education are intended to address one or more of three challenges facing education systems, namely how to: increase the number and quality of STEM graduates; improve the level of science literacy among all citizens; and promote the development of critical thinking and problem solving competencies. These three themes are not mutually exclusive, and can be seen as parts of a continuum. Ultimately, however, emphasis is often placed on one more than the others, leading to a prioritization of related recommendations, including the choice of whether to favour greater breadth or depth in STEM education.
Note: a number of publications made available through the Internet do not contain full publication information relating to the date of publication or the publisher. In the bibliographical entries below, likely publication dates are noted in brackets.


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