Student perspective of STEM education in Canada

Strategies and solutions from an expert-led working group

November 7th, 2016

" Science, by itself, provides no panacea for individual, social, and economic ills. It can be effective in the national welfare only as a member of a team, whether the conditions be peace or war. But without scientific progress no amount of achievement in other directions **can insure our health, prosperity, and security as a nation in the modern world."**

—*Vannevar Bush* [1]

The following report has been written in an attempt to provide a student voice on the state of STEM education in Canada and is based on the discussions of participants of the *Science & Policy Exchange* STEM working group event on November 28th, 2015 at McGill University, Montreal, QC, Canada

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Executive Summary

There has been substantial debate in the news media, and academic reports regarding the training of STEM (Science, Technology, Engineering, and Mathematics) students, particularly those with advanced degrees. Some **argue that STEM skills will play a critical role in driving innovation and productivity increases in Canada's future,** and therefore, we are not training enough STEM students. Others argue that difficulties faced by STEM students entering the job market suggest a surplus of STEM students. Missing from these conversations has been the voice of students currently engaged in STEM education. These students possess both first-hand experience in the current implementation of STEM curricula and a forward-looking view on the impacts this training has on their career preparedness.

On November 28th, 2015 *Science & Policy Exchange* convened a working group composed of STEM students and experts representing the perspectives of academic, government, and private sectors to discuss current challenges and opportunities in Canadian STEM Education.

Students voiced many issues on the current delivery of their STEM educations; these were broadly categorized as relating to curriculum and structure, critical skills development, career exposure, and metrics and evaluation. Briefly, students reported that:

- STEM classes are over-reliant on rote memorization and should include more active learning to promote development of skills required to apply this knowledge to diverse problems.

- They were often unaware of the career options available to STEM graduates, as well as the skills and experience needed for those careers.

- They had not developed the critical skills expected by employers, including communication, autonomy, and the ability to take risks.

- There was a lack of reliable information to evaluate schools, programs, and professors; this limits their ability to make informed choices for their academic and career paths.

Working with the experts, students also identified solutions to these challenges which could be implemented by universities and governments over the short and long term. Students affirmed that their STEM educations would be improved by:

- Reducing class sizes to improve student engagement.

- Developing interdisciplinary courses to expose STEM students to diverse perspectives for problem-solving.

- Increasing direct training in the critical skills that employers expect from STEM students.

- Fostering an early awareness of STEM careers and encouraging students to be proactive in forming a career plan.

- **Developing students' practical skills and professional networks through co**-ops and internship programs.

- Rewarding students with varied skillsets by improving graduate and undergraduate scholarship funding criteria.

- Establishing a centralized and transparent reporting system to track student progress, creating a metric for evidence-informed decision-making in future education policies.

- Increasing teaching support for faculty to allow them to focus on their research and mentorship responsibilities.

The specific policy recommendations outlined in this report broadly align with those of other reports on Canadian STEM education. By addressing these shortcomings, universities as well as policymakers, funding bodies, and other stakeholder groups can improve the quality, competitiveness, and learning experiences of STEM graduates and can better prepare them to enter the workforce. Overall, we found that students are excited to be involved in developing policies that will shape the education of future generations of STEM students. The student body should be considered a major stakeholder in education policy, and we recommend that this group be included in future discussions of policy development and reform.

Introduction

Science, Technology, Engineering, and Mathematics (STEM) encompasses a broad collection of disciplines including research in both life sciences (biology, medicine etc.), physical sciences (chemistry, physics etc.), technology (computer science, information technology etc.), engineering, mathematics, and statistics. STEM fields offer an understanding of the world around us, as well as technical expertise for a knowledge-based economy. Many of the significant challenges facing our society require a fundamental understanding of science and technology, and solving these challenges will require innovation and public policy guidance from STEM practitioners.

STEM education plays an important role in modern society, including creating and disseminating new knowledge and developing cognitive and communication skills. At the same time, Canadian universities serve as central providers of training for advanced vocational and professional skills. To this end, many universities and governments in Canada and internationally have been making efforts to advance STEM education at the undergraduate and graduate levels and to match the skills imparted to students with existing workplace requirements. For example, the NIH Common Fund BEST grant program aims to train graduate students in the United States for various career possibilities outside of academia [2], and the Mitacs Accelerate program facilitates joint industry-academic internship opportunities for Canadian graduate students, exposing them to the needs of the private sector [3].

Canada has the highest rate of tertiary education within the Organization for Economic Cooperation and Development (OECD) and among the highest rates of university completion [4,5]. Students in STEM fields represented 24.5% of all students and 53.5% among earned doctorates (PhDs). Despite this demonstrated high achievement in STEM education, Canada had among the lowest rates of productivity growth in recent years in the OECD [6]. **This disparity has provoked alarm from pundits and the national press, defining a "skills gap" or "skills mismatch" and outlining fears that Canada is training too many** PhDs and other highly skilled workers [7]. However, a recent analysis by the Council of Canadian Academies (CCA) [8] examining pre-existing literature and **Canada's educational and occupational data on STEM skills found no evidence of this skills mismatch; instead,** the analysis indicated that Canada has a well-functioning labour market and that STEM skills are necessary but **not sufficient for maximizing Canada's productivity. The findings of the CCA complement the findings of the** Conference Board of Canada (CBoC) which indicated that, while Canadian PhD holders eventually have high workforce participation and wages, many face difficulty entering the workforce or start in low-wage positions in part because they are unaware of the transferable skills they have acquired through their training [9]. The difficulty that STEM graduates face entering the workforce is not unique to Canada; it is a common sentiment throughout most developed countries. Canada has the opportunity to be a leader in revamping STEM education, as these issues are quickly becoming relevant worldwide.

The voice of the group most directly affected by changes to education policy – the students – has been conspicuously absent from the conversations surrounding changes to the university system. Community engagement can reveal nuances that are not captured by large literature reviews. For instance, the CCA and the CBoC have authored reports on STEM training in Canada, but the broad conclusions of each report overlooked some issues that were important to STEM students.

Many students begin higher education with the expectation that it will leave them appropriately qualified for a successful career. However, they then find themselves doubting the ability of their degrees to secure them jobs within their field and feel unprepared for careers outside of their area of expertise. In an effort to better understand student perspectives, *Science & Policy Exchange* assembled a group of students with recent or ongoing experience in STEM university education, along with stakeholders from academia, government, and

industry to discuss the current state of STEM education and the ways it could better serve each group. This report was created from the proceedings of this conference.

" When you start a basic science degree you expect what you learn to be easily translated into an actual job but instead find yourself deep in the theoretical weeds. So by the end you wonder how you're qualified for a practical science job (if you can find one) let alone one that doesn't even share the theoretical weeds. It's become a cliché that we have little real-world education **or experience but at least we know that 'mitochondria are the powerhouse of the cell'."**

—*Matteo Bernabo*

Methods

To report on the students' voice and opinions, *Science & Policy Exchange* hosted a working group on STEM education on November 28th, 2015, bringing together students with experts in STEM fields across academic, government, and industry sectors. The goal of the event was to deliberate and devise guidelines to improve the way STEM training is imparted. Students were selected based on application essays designed to assess their ability to both communicate and discuss these issues in a group setting (application form in Appendix). Efforts were made to ensure that diverse backgrounds were represented, however the majority of students who applied and took part in the event were educated in biological sciences programs. This may reflect that these students expect the greatest challenges entering the workforce.

A total of 26 students were selected. The distribution of fields of study, education levels, and universities of origin are represented in Figure 1.
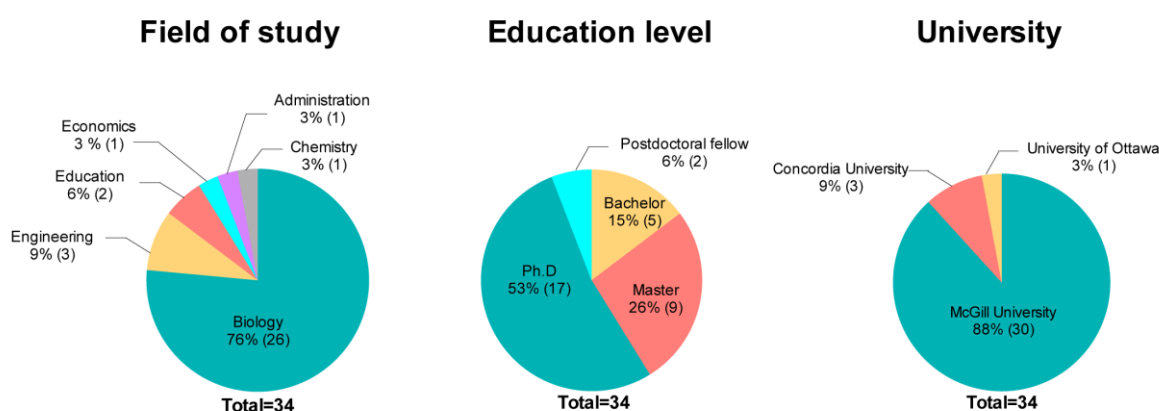

Figure 1: Field, education, and current university of STEM working group participants.

The *Science & Policy Exchange* STEM Education working group opened with remarks from Dr. Rémi Quirion, **Québec's Chief Scientist, who introduced** the keynote lecture from Sir Peter Gluckman, the Chief Science Advisor to the Prime Minister of New Zealand (hosted by Qué**bec's Chief Scientist and his office). Following the keynote** lecture, the students were divided into five groups based on their expertise and stated interests, with the objective of identifying challenges and solutions based on their experiences in STEM education from the **perspectives of 'government', 'large businesses', 'entrepreneurs and small and medium-sized enterprises', 'natural sciences', or 'applied sciences'. Experts representing each group were present to guide the conversation,** answer students' questions, and lend their perspectives as experienced members of their fields. Each group had at least one expert for their topic and a member of *Science & Policy Exchange* present during the discussions.

The working group was divided into multiple sessions; the first was dedicated to identifying major challenges facing post-secondary STEM education in Canada, in particular those creating obstacles to employment. Next, students were encouraged to develop specific solutions and strategies for their implementation. Finally, to integrate these strategies into clear recommendations for improving Canadian STEM education, new groups, composed of one student representative from each group were formed, in which each representative presented the findings of their original group for greater discussion.

Notes taken by *Science & Policy Exchange* members and audio recordings from each table were used to guide the writing process following the event. The notes and audio recordings were reviewed to identify the challenges and solutions voiced by the student participants. These were then grouped into the unifying topics, which are presented in this document. A number of participating students were involved in the writing process, and each participant and subject matter expert was given the opportunity to review and approve this white paper.

Challenges Facing STEM Higher Education

The students in the working group identified many issues that they felt impaired the quality of their education or limited their employment opportunities after graduation. For the purposes of this paper we have focused on issues raised by multiple students or that seemed particularly endemic. These challenges were categorized broadly as those relating to (1) Curriculum and structure, (2) Critical skills development, (3) Career exposure, and (4) Metrics and evaluation.

Curriculum and Structure

Large Class Sizes

In early undergraduate courses, large class sizes have become the norm. These large classes can limit verbal participation, active engagement, interactive learning among peers, and individual accountability [10-13], and this was reflected in the experiences expressed in our working group. Large class sizes make the incorporation of group projects logistically challenging and limit the pool of efficient assessment methods, as evidenced by the widespread reliance on multiple-choice exams. This has created a bottleneck through which many large classes rely on rote memorization to evaluate the comprehension of course material. Memorization and comprehension are not synonymous, however; success in problem-solving is indicative of more meaningful learning, and facilitates the application of concepts to new problems [14]. This is compounded by the observation that larger class sizes negatively impact retention compared to smaller, more socially integrated groups [15].

Lack of Applied Learning

The emphasis on rigid theory-based coursework in STEM curricula also tends to shuttle students toward an academic career path by default. Such a dominant focus on select career paths may ultimately discourage young people with a broader interest in STEM fields, who often find themselves ill-equipped for the job market outside of academia[16]. Many students found that their undergraduate programs did not increase their awareness of non-academic career options, as they did not provide sufficient opportunities for students to either interact with professionals in these careers or gain relevant work experience. Furthermore, students found that the relative rigidity of STEM curricula makes it difficult for them to seek out courses that would provide them with complementary and critical skills necessary for the workforce. STEM students also reported that they have very few opportunities to work with people from other disciplines, or to learn to integrate their STEM skills and academic mentality into more complex real-world problems. Similarly, Arts and Humanities students rarely have the opportunity to interact with STEM students, which may contribute to the undervaluing of STEM skills in other sectors. Even for STEM students who do wish to pursue graduate degrees, a curriculum of predominantly theory-based lecture courses provides little practical training for graduate research environments.

> **"** Management students also have 600-people classes but the way the professors do it is break **[students] up into teams... they actually have to work together, whereas in science we all show** up individually as 700 people and then we leave as individuals. We never interact with each other ever**"** —*Hicham Mahboubi*

> **"** Memorizing the detail is less important than understanding the process**"** —*Chelsea Cavanagh*

Critical Skills

Throughout the event, students consistently identified insufficient development of critical skills as a major shortcoming of their respective academic programs. Broadly, critical skills include leadership

and management, teamwork, communication and interpersonal skills, the ability to deal with failure, and creative problem-solving (full list of identified critical skills in Appendix). These skills are transferable across work environments, academic or otherwise, and are therefore vital for success. Traditionally, these skills have been classified as "soft" skills, in contrast to "hard" skills, which are typically field-specific and measurable. Due to the importance of these skills, the working group defines them as "critical" rather than "soft".

Focus on Research Skills

Problematically, young students tend to not recognize the value of critical skills until they face the job market [17]. This phenomenon is in part due to the typically discipline-specific skills required to succeed in academia. Compounding the problem further, students in graduate education are commonly pressured by their supervisors to focus on their academic work and receive little encouragement to seek out opportunities to expand and diversify their skillsets. This type of educational environment develops graduates who are highly proficient in very specific tasks. In contrast, employers have stated that critical skills such as communication, leadership, management, and teamwork are more important assets for getting hired and career advancement [18]. This is particularly true in industries that provide on-site training for job-specific skills. Indeed, a Workopolis research report found that, although Canadians have been adding more education to their resumes, education is not what employers are looking for. Rather, communication skills were the most sought after skills in Canadian job postings in 2015 (Figure 2).

Figure 2. Word cloud of high demand skills for Canadian job postings.[18]

Underdeveloped Communication Skills

Alarmingly, working group participants, both students and experts alike, identified communication skills as a particular shortcoming of the STEM training program. A deficiency in basic communication skills can manifest in a variety of ways, ranging from poor professional interpersonal skills to an inability to generate documents that are both logically and structurally sound. Moreover, it was noted that STEM graduates, compared to their contemporaries with Arts degrees, tend to lack the narrative language required to successfully market

" **I have friends who can tell me their research in huge detail but if I'm not in that field I have no idea what they're talking about. So even if you're in it, you don't necessarily know how [to communicate it]"** —*Emily Brown*

themselves to potential employers. Unfortunately, the current classroom structure is not conducive to teaching appropriate communication skills that facilitate teamwork and collaboration; typical undergraduate classes do not foster community and are instead perceived as impersonal and isolating [19]. Coursework in most institutions places emphasis on the student working alone, which prevents the development of interpersonal skills and limits their exposure to a diversity of potential solutions.

Risk Aversion and Fear of Failure

Students of the working group further voiced that the focus on degree specialization, coupled with the rigid curriculum and emphasis on grades, minimizes opportunities for personal development and often leads to insecurity and an inability to pursue high-risk or innovative thinking. Although there is evidence that active **learning paradigms in which students are incited to engage in discussions through group discussions, "clicker"** questions, and challenging extracurricular assignments are more successful in developing these critical skills, departments and professors have been slow to adopt them [18, 20]. In rote learning, each problem or question is linked to a clear solution and, should difficulties arise, the instructor can be depended upon to provide the appropriate guidance. This does not adequately prepare graduates for real-life problems, as it leads them to struggle in developing new approaches to problems and in implementing solutions to complex situations [14]. This is particularly alarming, given that accepting risk is a key factor for entrepreneurship and innovation. Indeed, despite an increase in venture capital spending and a number of changes in innovation policy in recent years, Canada consistently ranks low on the innovation scale compared to similar countries, in part due to under-investment in riskier innovation activities and insufficient cross-talk between universities and industry [20, 21]. To develop entrepreneurs, it is necessary for students to learn the value of failure.

Career Exposure

> **"** It's the worst-kept secret in academia that most trainees won't end up as academics. There's a disconnect between faculty and students who believe a university is for higher learning vs job preparation, respectively. We're all told 'you go to university to get a good job'. We therefore expect to leave university with job-ready skills and knowledge. The problem is that we don't just lack job-ready skills and knowledge, we're never even educated on how to get those skills and knowledge in the first place!" —*Matteo Bernabo*

> **"** My dream job is to lead my own research group, preferably in the tenure track and in Canada, but it's a tough road ahead when you see the sheer number of qualified postdocs and graduate students vying for only a handful of competitive positions. I'm still going for it, but I know it would be foolish to do so without a plan B." —*Shawn McGuirk*

Lack of Career Preparation

Another major challenge that had been encountered by many students at the working group was a lack of active career preparation throughout their STEM training. Particularly at the graduate level, exposure to careers outside of academia is often limited, making it difficult for students to make informed decisions in their career path [9]. Compounding the problem is the culture in which non-academic careers are worth inherently less than the academic path, and that seeking opportunities outside the laboratory merely diverts focus away from research. Many graduate students at the working group felt unaware of what skills were needed in the sectors **outside of research. Furthermore, students' perceptions of career options are not in line with the current job** market. Many graduate students expect that they will pursue a career in research, yet in some fields, such as biomedicine, the chances of obtaining a tenure-track professorship are as low as 1 in 6 [5, 18].

John Holdren, US Presidential Science Advisor, was recently quoted saying, "If every PhD we train believes that her or his only acceptable career trajectory is a tenured professorship in a college or university, then it's true: we are training more PhDs than there are slots of that kind. But the PhD is, in fact, a very versatile degree. Far more than just demonstrating that you know more than practically anybody else about one narrow topic, it demonstrates that you have the fortitude, the focus, the commitment and the intellectual capacity to tackle a very tough problem" [22]. While these qualities would certainly be beneficial outside of academia, there is little awareness on the part of graduates of how to translate the skills they have developed to potential employers, as well as on the part of employers who may not have an understanding of the requirements of graduate research and who are often unaware of the valuable contributions that can be made by someone with a STEM education. Taken together, this makes for a particularly challenging transition for graduates entering the workforce [9].

Shortage of Tailored Career Services

While most universities have a career planning service available to offer mentorship and advice, our working group participants found that the career services available to them were insufficient. In many cases where help was sought, advisors could not provide the information requested, or were unaware of even mainstream career options for STEM students. For instance, one student at the event who was pursuing a Master's of Science was looking to transition into a career in the private sector and was assigned a career counselor primarily for undergraduate arts students. The student felt that this support was inadequate - the counselor was not familiar with the academic path of a science graduate, nor the career opportunities outside the student's field. There is a need for guidance counselors who understand the nature of the field of study and who can provide insight about the national employment market. Students also voiced a lack of career exposure during their undergraduate and graduate studies, particularly early on in their degrees. Even in cases where career fairs were available, most students only realized the importance of career networking as they neared graduation.

> " My advisor, whose focus was in the arts, was not adequately knowledgeable at providing insight to people with my background seeking alternative career routes than academia, and the director of the mentorship program I joined did not know what the term 'entrepreneurship' meant. I was by no means impressed with the career planning services and **resources available to me."** —*Christian Gualtieri*

> " The resources available to us are far from sufficient. There are no placement programs to help us make contact outside of our academic environment and our supervisors do not allow us the time to explore and sometimes become aggressive with us if mentioned. Graduate school only prepares one for an academic career, but what is the use if only 10% will ever manage to secure academic careers?" —*Yasmin D'Souza*

Metrics and Evaluation

Evaluating Students

At the undergraduate level, student rankings are assessed and compiled almost entirely on a single metric: the grade point average (GPA). Indeed, the GPA is such a critical marker for academic continuation that only students with perfect or near-perfect scores remain eligible for competitive graduate and professional programs, including medical school. For instance, the average GPA of new medical students accepted at the University of Toronto in 2015 was 3.96 out of 4.00 [5]. This is viewed as a major point of stress in STEM training, as students who are still considering both academic and non-academic careers paths feel discouraged from taking challenging courses or extracurricular commitments for fear of putting their GPA at risk. Emphasis on GPA forces students to

be perfectionists by creating the perception that failure is unacceptable. As stated at length in previous sections of this report, the ability to take risks and develop skills outside the central curriculum is critical for improving employment opportunities. It is therefore important that universities provide strong mentorship and career planning services for students, such that the pressure for the perfect GPA does not cause them to miss out on the many fruitful opportunities that the university community can provide. At the graduate level, evaluations by universities and funding agencies are predominantly based on a student's publication record, research objectives, undergraduate GPA, and supervisor track record, while only the most prestigious awards consider the student's involvement in extracurricular activities. Given that much of the cost of research is funded through grants awarded to the student's supervisor, evaluating students on the same metrics without consideration of their extracurricular leadership may not accurately reflect their overall achievements and goals.

Evaluating Faculty

The majority of higher education institutions in Canada have a single set of tenure-track faculty ranks and do not have dedicated ranks for faculty whose primary responsibility is teaching. While promotion and tenure policies of major institutions include the assessment of both research and teaching, in practice, faculty members must demonstrate "excellence" in research with a "competence" in teaching [23]. This may arise from the fact that research merit can be quantified through the amount of grant funding and number of publications whereas teaching quality is more difficult to assess and standards in policies are often ambiguous or undefined. Students in our working group observed that, as a result of pressure on faculty members to focus on research productivity, teaching practices and student mentorship obligations become a low priority. Indeed, while annual reviews of faculty are conducted both before and after tenure, the benchmarks for teaching excellence are less objective than those for research contribution and university service; teaching awards and contributions to curriculum play a role, but there is a heavy reliance on end-of-course student surveys as a proxy for teaching effectiveness [24]. In general, student surveys give an opportunity for students to voice grievances but seldom result in clear or constructive feedback for teaching improvement; this is reflected in research showing that these evaluations can be affected by the time of the day the class is held, class size, and class difficulty [25]. For this assessment to be useful, they must be designed and adapted for course context and must be addressed with strong institutional support [26].

Evaluating Universities

Many international and domestic students use university rankings as a means of choosing which institution to attend. Because of the relationship between rank and enrolment, university rankings are very valuable, and the metrics used to evaluate them are closely monitored [27]. Depending on the ranking system, a variety of attributes are used to determine the overall rank, including bibliometric data to evaluate research impact, student satisfaction surveys, and other data collected from the universities. However, Canada's public universities do not have mandatory structured reporting of many details, like class sizes and the amount of teaching done by faculty members, making a comprehensive comparison exceptionally difficult [28]. The metric that students may find most useful, career success, is not measured in any systematic way. While certain trade programs in colleges and even university programs, such as engineering, advertise 6-month job placement rates, universities as a whole do not track the career paths of graduates. Collecting these data, while challenging, would incentivize institutions to invest in career development resources and placement programs.

Strategies and Solutions

The following section discusses solutions that address many of the issues raised by the students. Many of these solutions address multiple problems. While some may be more difficult to implement or require substantial changes to curricula, other solutions could be implemented relatively easily in the short term. Not all of these solutions will be right for every institution, but we hope to provide a catalogue of ideas that could be tailored to each individual case. We believe that universities should first be incentivized to innovate and improve their programs from the ground up to have a maximum impact on the short term; in turn, support of such initiatives from governmental policymakers would be highly desirable in order to catalyze many of the cultural shifts needed in STEM education.

These recommendations are categorized as: (1) Reduce class size, (2) Build interdisciplinarity into the curriculum, (3) Integrate "skills for today", (4) Increase teaching support for faculty, (5) Increase student exposure to diverse career paths, (6) Increase opportunities for co-op placements and internships, (7) Modify the criteria for student funding and scholarships, and (8) Establish a centralized and transparent reporting system to track student progress.

Reduce Class Size

Many studies have highlighted the deleterious effects of large class sizes on retention, student outcome, self-reported learning experience, and instructor rating [11, 13, 15]. Large lecture courses are found across all faculties, but they are particularly prevalent among early undergraduate level STEM courses. Indeed, negative learning experiences from large lecture courses were a common theme arising from the student working group. Students found smaller courses and increased contact with teachers to be more personal and engaging, improving their learning experience. Decreasing class size, more specifically the student-to-instructor ratio, increases the time and resources that can be allocated to each student and allows instructors to be more invested in a given student's outcome. Furthermore, small classes are more amenable to in-class participation, which helps nurture confidence and transforms students from passive recipients to active participants in the learning experience. Students experienced a greater sense of community in smaller classes, facilitating group projects, presentations, and laboratory sections, leading to more meaningful and applied knowledge. The incorporation of experiential and problem-based learning would help students develop critical skills that will be essential in the workforce. Faculty at many schools have also begun experimenting with the "flipped classroom" approach, where students watch the lecture at home and work on solving problems in the classroom [29]. While many faculties have found success with this approach, even in large courses, it was not discussed at length in our working group, and it is possible that no students present had experienced it. We recognize the amount of work required to implement these alternative teaching approaches, or to reduce class size, and outline some possible solutions in the *Increasing Teaching Support for Faculty* section below.

> **"** A great advantage associated with smaller class sizes is that it provides space and time for group discussions. These conversations bring learning to a higher level, from remembering and understanding to analyzing and applying, making the class and content more memorable." —*Jennifer Barrow*

> **"** When I think back on my undergraduate studies, the only courses I can recall with any detail are the ones with smaller classes. These were the classes where I felt personally challenged and invested because my participation contributed to our collective learning experience."
> —*Vanessa Sung*

Build Interdisciplinarity into the Undergraduate Curriculum

Working in a group of people with diverse backgrounds generates a more creative and productive environment [30]. Courses bringing together STEM, arts, and humanities students may encourage more innovative thinking in students and can increase their openness to new perspectives. This supports a growing movement towards **reclassification of STEM to "STEAM" through inclusion of the Arts**, which has been proposed to support the development of communication and creativity skills in STEM graduates [31]. Many Canadian universities currently offer interdisciplinary programs, allowing students to take a mixture of arts and science courses, but there are far fewer classes bringing these groups together; the few that do have been brought about through bottom-up teacher initiatives. We recommend that institutes investigate formalizing these courses and encourage their expansion; however, we recognize that this may be time-consuming and costly. A current initiative underway at McGill University is the introduction of a Minor in Entrepreneurship across multiple faculties. This type of program will be especially beneficial if it is applied in a way that encourages students from different faculties to attend the same courses and work together.

A simpler way to broaden the scope of STEM students' education and to introduce big-picture thinking is to host guest lectures by professionals from different STEM-adjacent sectors. For example, in a biochemistry course, guest lecturers might include a pharmaceutical product developer, patent lawyer, clinician, or a policy analyst in order to facilitate a better understanding of how discoveries made in academia translate into society. More importantly, students would gain deeper insight into the process of STEM innovation, learn about various non-academic careers that benefit from a background in STEM training, and ultimately become better positioned to make informed decisions regarding their own education and career paths. At McGill University**, the "Business of Science" course has a different field expert for every lecture, including patent lawyers, health policy experts, and** clinical researchers, such that students are encouraged to study a scientific issue from a business perspective.

Integrate "Skills for Today"

A relatively simple way to help prepare students for the workforce is to provide training that incorporates skills needed for modern challenges. As outlined by **a recent Workopolis report, which states that "digital literacy is the new literacy," knowledge of software that is commonplace in a field of study is often an expectation for** graduate school and for job applicants. The top rising in-demand skills in 2015 were centered on digital fluency, including knowledge of HTML5, MongoDB, Google analytics, and big data analysis [18]. Students voiced that these skills should be offered across disciplines, not just in Computer Science.

> **"** Both for careers in and out of academia, digital literacy is unquestionably valuable, and universities are failing STEM students by making so little effort to give us these skills. Having basic coding and computer science courses integrated into the undergraduate curriculum would at least give us the foundation to learn more specific skills at higher levels as they are **required, and (…) understand the software we us**e in our research." —*Daryan Chitsaz*

Some students felt that taking a certain number of basic skills development courses should be part of the mandatory curriculum, as long as there were a wide range of options available. Indeed, giving students this option would have the added benefit of encouraging them to plan ahead and consider which skills they will need in the future. Perhaps more realizable is the inclusion of courses aimed at developing critical skills which **can also provide complementary knowledge to the student's core curriculum; this is advantageous for students** aiming for careers both in and out of academia. For instance, hands-on programming courses can improve the problem-solving skills of students in the natural sciences while preparing them to face the analysis of big data, creative writing courses can hone communication skills in the real world as well as for writing research papers,

and learning the fundamentals of management can prepare students vying to be entrepreneurs as well as those wishing to craft a well-rounded graduate thesis. Moreover, the implementation of a pass/fail system for these **electives would minimize the risk of damaging one's gra**de point average (GPA). It is important to emphasize that the removal of a grading system should not reduce expectations; instead, this should put learners in high-expectation situations where they are asked to solve problems for which instructors do not provide solutions, rewarding understanding, originality, and rigor. A student-**driven initiative at Queen's University has applied this** principle, allowing Arts and Science students to take courses outside their curriculum on a pass/fail basis [32].

Extracurricular workshops for other critical skills, such as leadership, confidence, and communication would also help STEM students broaden their skillset, and formal training in global scientific literacy in addition to specific skills for writing literature reviews, communicating science to lay audiences, and scientific writing would be an asset to graduates. Although several relevant workshops are already available in many Canadian universities, such as the Graphos and Skillsets series at McGill University, they could increase their impact by being accessible to more students. These initiatives are difficult to fit in often-crowded schedules. Increasing awareness of the benefits these programs can convey, in addition to emphasizing the importance of these skills as well as digital literacy for careers both within and outside academia, should be of particular consideration for universities, individual faculties, and departments therein.

Increase Teaching Support for Faculty

Many of the issues raised by students were perceived to arise from overworked professors, spread too thin between their research, teaching, and mentorship responsibilities. These unmanageable workloads can be alleviated through increased support for faculty members; this can be applied with minimal increases in overhead costs through opportunities for graduate student teachers. Indeed, graduate students with teaching experience possess better research skills in general [33] and are better qualified for academic positions. This approach would simultaneously allow graduate students to gain teaching skills while lightening the load for faculty, who can then put more focus on research and mentorship. For example, Biology PhD candidates at Concordia University are required to complete a course in pedagogical training that culminates in teaching an undergraduate class. Another change that could be implemented, albeit with more financial investment, is to create more dedicated full-time teaching positions (or teaching assistants). This could mean having two tenure track positions for Professors, one for research and another for education. Although this format has been met with some debate, proponents maintain that teaching-only professors would result in better quality learning for students and also allow researchers to devote more time to the graduate students in their labs and their research [34]. This increase in time dedicated to research may also be cost-effective, bringing more publications and funding to the university [35]. Critics argue that this format of tenure tracks renders university professors no different from high school teachers, stressing that learning at the university level is best when it comes from active researchers [36]. However, studies have suggested that students in fact learn better from non-tenure track faculty [37] and York University, McMaster University, University of Victoria, and University of Toronto have all begun implementing this teaching stream [24].

While this debate is beyond the scope of the present report, the opinion of the students at the working group was clearly in favour of dedicated teachers. If this format were adopted, one suggestion was to bring in researchers to give guest lectures in courses. Further support for research teams could be incorporated through management staff who could aid in tasks, such as grant writing as well as laboratory management. The addition **of these support staff positions would create jobs and, importantly, opportunities to employ Master's and PhD** graduates having difficulty finding employment. Finally, integrating pedagogical workshops and evaluations as **a regular ongoing aspect of a professor's tenure portfolio would provide a mode of internal quality control, as** well as a platform to explore improved and innovative teaching practices.

Increase Student Exposure to Diverse Career Paths

In the university setting, students are primarily in contact with other individuals in academia and have limited exposure to the private sector. Some initiatives have addressed this issue, including the GradProSkills workshops at Concordia University and networking events by groups such as Mitacs, Biotech Annecto, and *Science & Policy Exchange*. Students suggested several additional approaches to increase exposure to alternate career paths during STEM training. Given that even research-intensive graduate programs in universities have regular, and often mandatory, talks and seminars from academics, expanding the roster of speakers to include those having had success outside of academia can raise awareness about and generate interest in these careers. Additionally, "idea fairs" where students and laboratories present their ongoing projects to interested local businesses could be a way to develop partnerships and foster innovation by promoting ties between universities and industry; this also presents an opportunity for students to hone their communication skills. Another suggestion was to create a position within the university responsible for liaising with local businesses to help develop collaborations and encourage placement of students into fruitful internships and co-op programs. At the working group, experts representing small and large business alike believed this approach would be a win-win, allowing industries and start-ups to connect with students for potential future employment.

Career services could also work with students to create career plans similar to the My Individual Development Plan framework created by the American Association for the Advancement of Science (AAAS), which could support students in choosing internships or skills-based courses. This would be facilitated by career advisors dedicated to specific STEM fields and levels of training. On a more general level, the organization of networking events could also be added to the career services mandate of universities. This can include support for student initiatives; senior students often seek to organize lectures from alumni in order to learn from the job market transitions of past graduates. In this way, students would be challenged to consider their career goals at the very beginning of their graduate studies rather than focus only on their theses. Career exposure opportunities should be made available to students of all levels, for those nearing graduation whose pressure to find a job is greater and particularly for younger students such that they can better plan ahead.

Co-op Placements and Internships

Several Canadian universities, such as the University of British Columbia and Waterloo University, have heavily invested in developing large co-op and work experience programs. Along with federally- and provincially-funded opportunities such as the Federal Student Work Experience Program (FSWEP) and Mitacs fellowships, these programs provide a valuable complementary experience to traditional curricula and help students acquire the critical skills that many felt their STEM education lacked. Work programs also benefit university and industry partners by increasing job placement after graduation and by giving businesses access to promising talent that they can train early on. Both undergraduate and graduate students would benefit from such workplace experience. To encourage universities to develop and promote such programs to their students, federal and provincial governments could incentivize universities and employers through increased funding or tax credits based on the numbers of students enrolled in such internships. It should be noted that experience working in research laboratories should also be promoted, as this can be uniquely valuable for students considering a career in academic or industry research. Increasing the availability of co-ops and internships is not intended to dissuade students from obtaining academic lab experience, rather it provides an alternative form of hands-on learning for students who wish to explore non-academic paths.

A particular emphasis must be made on the importance of student awareness of programs; this is vital to their success. During the event, many students reported that they would have greatly benefited from participating in these programs, however they were not aware of their existence. Many participants nearing the end of their degrees learned of programs for the first time while at this event, to their disappointment. In addition to

advertising through career services, a platform or career concierge that collects and updates all information on public programs and career development opportunities would be an advantage for many students.

> **"** [Existing] events and seminars are not well-attended. I think one of the problems is really the **mindset of the science student. Students often don't proactively seek out [resources]… 1) They're not aware or 2) don't want to spend the time [because they are focused on grades]."**
>
> —*Sharon Yang*

Modify the Criteria for Student Funding and Scholarships

The Canadian government has a history of using leadership and critical skills as a requirement for its most prestigious scholarships, including the Vanier Canada Graduate Scholarship at the graduate level and the now defunct Canada Millennium Scholarships program at the undergraduate level. However, the majority of student funding administered through tri-council and provincial grants is based solely on academic achievement and research potential as measured by the project description, publication record, and project supervisor. While the academic record and the quality of the proposal remain important, the final rank of each fellowship application **should also reflect the student's rationale of how their research project will help them succeed beyond their** graduation, as well as how they plan to acquire the skills required to complete their thesis and reach their long-term goals. Research funding should also be more distributed among students with exemplary records of teaching, leadership, entrepreneurship, or other skills, to reward and encourage students with diverse skillsets to remain in STEM research and to demonstrate the value of these skills to the STEM community. This could be implemented through changes to the current granting scheme, or through the development of new funding opportunities.

Establish a Centralized and Transparent Reporting System to Track Student Progress

Reliable and accurate metrics are a crucial component of improving STEM education through evidence-based policies. One of the most important metrics for success is student placement after graduation. Although general reporting has been done on student outcomes using survey or census data, these were not comprehensive and often did not distinguish among different forms of employment such as post-doctoral fellowships or industry [37]. Additionally, there is an absence of prospective studies that follow stud**ents' career path**s after graduation, making it difficult to determine what interventions will be necessary or most effective in improving student outcomes. The ability to collect and analyse data on individual students and teachers, as well as institutional data on teaching practices and student outcomes, is more feasible than ever before. Universities already collect large volumes of data about students that, if centralized, could be leveraged to make effective evidence-informed decisions that improve the outcomes of STEM students. For instance, The University of Colorado used a **"ribbon-plot" tool developed by the University of California Davis to track where students started and ended. In** an effort to reduce attrition of majors in the STEM fields, the data **on students' course enrol**ments, grades, and major over time were used to visualize student trends after a particular course was taken, a grade received, or based on student characteristics such as gender and race (Figure 3).

On a larger scale, the TRaCE project, a collaboration of humanities and social sciences departments from 25 Canadian universities, has begun to track the employment of Humanities PhD graduates and the paths they took to get there [38]. With these data, they will not only be able to understand how graduates obtain jobs and their contribution to the economy, but will also develop a network that will bring impact back to current students.
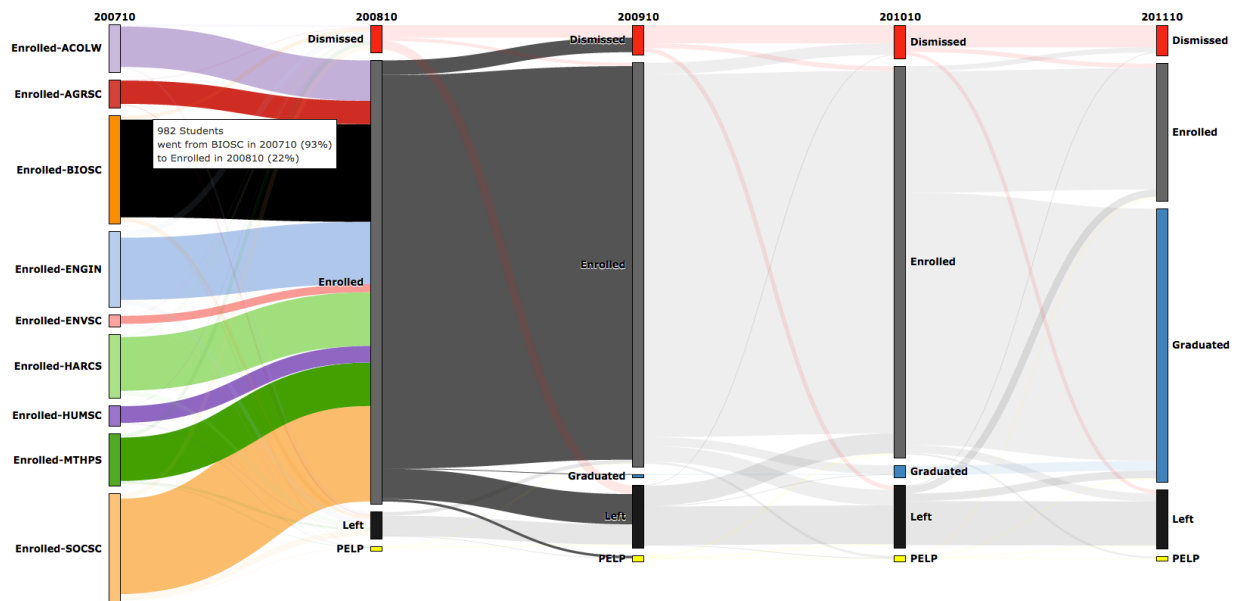
Figure 3. Ribbon-plot tool used to track student enrolment, grades, and major at the University of Colorado [39]

Implementation of an anonymous universal student identification number or linkage of these data to established identification standards would allow for comparison of teachers, departments, and institutions nation-wide, as well as the identification of current best practices and areas for improvement. Given the privacy risk of using current identifiers like social security numbers, this would likely require the development of a new identification system. Extending the data collection to track students long past graduation would provide students with a realistic idea of the labour market while offering institutions valuable insight for creating strategies that better prepare students for their careers. Given the limited resources for funding competitions, long-term longitudinal data would maximize their return on investment. This also extends to funding for research laboratories, where accurate outcome reporting would ensure funding agencies that their allocations have supported successful trainees in a variety of career paths in addition to the base research goals. Making these data publicly available would also incentivize schools to invest in career development opportunities for their students, as high quality job placements could be used as an effective marketing tool. With accessible data, prospective students would be better informed when making decisions about where to obtain the best education and how to use it once they have graduated. It is anticipated that institutions may resist being the first to institute public reporting of this information if they fear it will put them at a competitive disadvantage. Provincial governments could catalyze this process by developing standardized reporting systems and making some continued funding dependent on their implementation.

Conclusion

This white paper brings together the perspective of students from various fields on a number of issues that directly affect them and STEM education. Although this topic has been discussed at length in the media and in other reporting, the input of students is important as they offer the value of first-hand experience. It is clear from our working group that students are not passive participants in their own education. Students are attentive to the challenges they face entering the job market and want to be involved in developing policies that help shape the future of Canada's innovation ecosystem. In general, students feel unprepared to enter the workforce. Although we acknowledge the long-term benefits of STEM education, we cannot disregard that the transition from graduation to employment is a nebulous one.

The students of this working group support several short- and long-term initiatives to facilitate the process of bridging this gap. In the short term, developing an early awareness of the breadth of careers that benefit from a STEM education and of the complementary skills they require would help students be more proactive in their career development. Individual faculty members looking to make a difference can have a large impact by adding interdisciplinary content into their courses, developing courses that take advantage of modern technology to increase student engagement, and encouraging students to enroll in existing skills development workshops. To support individual faculty members in this process, greater teaching responsibilities could be taken on by graduate students and more constructive student feedback on learning experiences should be integrated into course evaluations. Institutions will benefit from formalizing these processes and making them standard components of their curricula.

The most commonly proposed change in our working group was to increase practical learning through co-op placements and internships. While these programs may be resource-intensive to develop, they provide long-term benefits to students, schools, and local industries by fostering hands-on experience, industry contacts, and a highly trained workforce. Moreover, these programs increase the exposure of employers to the value STEM students provide, including analytical and problem-solving skills. Institutions should be encouraged to experiment with developing programs that engage students in the local economy. In the short-term, funding agencies, institutions, and industries alike should better advertise funding opportunities which support workplace internships.

In the long-term, establishing a centralized database to track student progress and to collect data on students, university programs, and job outcomes will dramatically improve program development and evidence-informed education policies. This will be vital for determining which programs are successful in improving student educational experiences and employability.

The recommendations of the students broadly align with those of past reports including those by the CBoC [9] and CCA [8]. These reports reiterate the importance of the recommendations brought forth by several major Canadian institutions and make suggestions to improve a fundamentally functional educational system and labor market; students' perceptions of the status quo are however much more bleak. These concerns have been echoed by a recent focus group of graduate students and post-doctoral fellows organized by the Higher Education Quality Council of Ontario in partnership with Academica and Mitacs [40]. It is possible that students are unaware of the reality of the market for STEM students, or that aggregated data across fields provide a misleading picture. In either case, to address the disconnect between students' experiences and the perspectives described by these reports it will be crucial to improve the preparedness and awareness of STEM students for non-academic careers, as well as the evaluation of the programs providing this training.

Finally, the experience of this working group clearly demonstrated the desire of current STEM students to be involved in the policymaking processes that will impact them and future generations of STEM students. It is important that students be consulted, and their views taken seriously in future policy analysis and development.

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About *Science & Policy Exchange*

Who we are

Science & Policy Exchange (SPE) is a Montreal-based and student-run nonprofit organization. SPE provides a much-needed forum for discussion of scientific issues to inform policy at the provincial and federal levels. Our mission is two-fold:

- To bridge the gap between academia, industry, government, and students to encourage evidence-informed policy-making.

- To engage and inform the general public who feel the impact of these policies.

What we do

Since 2010, SPE has provided a platform to foster discussions between stakeholders and to inform the public about outstanding issues in science policy. The SPE conference, held yearly from 2010-2014, established our reputation for meaningful discourse on the proceedings of Canadian policies. In doing so we have extended our reach to Québec policy researchers, students, and stakeholders from all fields by covering a broad spectrum of topics through invited keynotes and panels.

In recent years, SPE has matured from a student group into a registered charity with a broader sphere of influence and a governing board of directors in order to pursue direct policy issues. We continue our student outreach through networking events, to empower and drive interested individuals towards action and change. We engage the public through public forums, sparking discussions on hot topic issues between experts and the lay audience. Finally, we aim to drive positive policy changes and promote the student voice through expert-led working groups, such as the one presented in this report.

Our impact

SPE is the only organization in Québec that equally addresses the interests of academia, industry, government, students, and the public on provincial policy concerns. We have consistently engaged our audience of students and public through talks and discussion forums where they interact with scientists and policy makers on topics as diverse as renewable energy, public health, and entrepreneurship.

Science & Policy Exchange helps Québec and Canada thrive by facilitating discussions
to drive evidence-informed decisions.
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Application Instructions

Application deadline: **Tuesday, November 10th, 2015 at 17:00 EST**

Answer the following questions within the indicated word limit. Save completed applications as a Microsoft Word document with the file name: **firstname_lastname_application** and submit it along with a **curriculum vitae** (maximum 2 pages) saved as **firstname_lastname_CV** to spestemevent@gmail.com.

1. Please describe the qualities that you possess that would make you the ideal candidate to voice the student perspective at the Science & Policy Exchange Working Group on STEM Education (250 Max).

2. What are your long-term career goals and how will this experience contribute to meeting those goals (250 Max).

3. What do you believe is the biggest issue facing STEM fields today? What are the potential solutions to the challenges you identified? (500 Max)

If you are selected, you will be asked to join a discussion group on a specific topic. Please rank the following topics in order of preference (1 being the discussion group would you **most** like to take part in and 5 being the discussion you would **least** like to take part in).

_____Government policies

_____Start-up companies/entrepreneurship

_____Big business/industries

_____Natural Sciences (e.g. biology, chemistry, physics)

_____Applied science (e.g. technology, engineering, computer science, mathematics)

Appendix | Full list of critical skills (alphabetical)

- Ability to apply knowledge to hands-on work
- Acceptance of uncertainty and/or risk
- Adaptability and flexibility to new situations
- Awareness of skills and self-marketing (students are not always aware of the skills they have developed, nor how to present these to employers)
- Communication
- Confidence
- Critical thinking / creative problem solving
- Dealing with and learning from failure
- Independence
- Leadership
- Self-directed learning
- Self-regulation and time management
- Teaching
- Teamwork