UNIVERSITY of GUELPH

COLLEGE of ENGINEERING AND PHYSICAL SCIENCES

December 14, 2018

The Honourable Lisa Thompson
Huron Bruce MPP
Minister of Education, Ontario

Dear: Honourable Minister Thompson,

Enclosed please find a proposal we are submitting as part of your consultation process on K-12 education in Ontario. Our proposal entitled "**Closing the Gender Gap in Engineering – the Role of High School Physics"** outlines the current pipeline of Ontario students who are taking the required science and math courses to subsequently enroll in postsecondary engineering and physics programs.

Using enrollment data from the Ministry of Education, we highlight the large gender imbalance seen in grade 11 and 12 physics. This issue then carries over into postsecondary engineering and physics programs, and later their associated professions – limiting our provinces ability to produce a talented workforce. Working in partnership with postsecondary institutions, K-12 educators, school boards, and your ministry, we believe this is an issue which can be readily ameliorated.

The timeliness of this initiative also coincides well with the 2018 Nobel Prize in Physics, awarded to Professor Donna Strickland at the University of Waterloo. Professor Strickland is only the third woman to win the Nobel Prize in physics and the first Canadian female scientist to do so. This is remarkable considering 209 physicists have been honoured since the Nobel Prize was first awarded in 1901. Professor Strickland stands as an exemplar and inspiration for students across Ontario, proving what is possible for all our students in the field of physics.

This topic is of great importance to postsecondary institutions across Ontario as well as the engineering and physics professions across Canada. Acknowledging this, several organizations have endorsed this report and our recommendations by adding their signatures. These include:

The Ontario Society of Professional Engineers (OSPE) - The Ontario Society of Professional Engineers (OSPE) is the voice of the engineering profession in Ontario. They represent the entire Ontario engineering community, including professional engineers, engineering graduates, and students who work or will work in several of the most strategic sectors of Ontario's economy.

Canadian Association of Physicists – The Canadian Association of Physicists (CAP) represents the voice of the Canadian physics community, pursuing initiatives that enhance the vitality of physics and the contribution of physicists in Canada.

Ontario Association of Physics Teachers – An organization of secondary and post-secondary physics teachers and students whose mission is to advance the teaching of physics in the secondary schools, colleges, and universities of Ontario.

Engineers Canada – Engineers Canada is the national organization of the 12 engineering regulators that license the country's 295,000 members of the engineering profession. They work to uphold the honour, integrity, and interests of the engineering profession – advancing the profession in the public interest.

Engineering Change Lab – The Engineering Change Lab is a collaborative platform, allowing leaders and organizations from across the engineering community to share perspectives, deepen understanding, and take action to address systemic challenges holding back the engineering profession's full potential.

Ontario Network of Women in Engineering (ONWiE) – ONWiE was formed in 2005 between all the schools and faculties of engineering across Ontario. The objective of this network is a collaborative effort to support current female engineers, students, and encourage the next generation of women to pursue careers in engineering.

Council of Ontario Deans of Engineering (CODE) – A council representing the Deans of accredited Engineering and Applied Science programs across Ontario.

As the authors of this report, we have been collectively working in the areas of women in engineering and physics and physics education for over twenty years. We believe we are knowledgeable and well equipped to address these issues and look forward to working with you in partnership on this important topic.

Sincerely,

Mary Wells

Mary Wells, Dean, College of Engineering and Physical Sciences, ONWiE Chair 2013 - 2018

Martin Williams, Associate Professor, Physics

Eamonn Corrigan, OCT, PhD Candidate, Physics

V. J. Davidson

Val Davidson, Professor Emerita, Engineering

UNIVERSITY of GUELPH

COLLEGE of ENGINEERING AND PHYSICAL SCIENCES

Closing the Gender Gap in Engineering and Physics
The Role of High School Physics

Mary A. Wells
Dean, College of Engineering and Physical Sciences, ONWiE Chair 2013-2018

Martin Williams
Associate Professor, Physics

Eamonn Corrigan
OCT, PhD Candidate, Physics

Valerie Davidson
Professor Emerita, Engineering, ONWiE Founder

December 14, 2018

Executive Summary

Attracting more women to the fields of engineering and physics is essential to maximize innovation, creativity, and competitiveness in Ontario. The quickest and cheapest way to increase economic productivity within the province, is proper utilization of resources already present. Thus, increasing female representation is a value proposition from both a business and innovation perspective, resonating deeply within government organizations, professional engineering bodies, and academic circles.

The critical point where the largest number of potential female engineers and physicists are lost occurs in high school, specifically in the physics classroom. Of all female students who have completed the required Grade 10 Academic Science in Ontario, only about 15% enroll in Grade 12 Physics compared to 30% of male students. This corresponds to a female participation rate of only 34% in the physics classroom – a trend seen over the past decade. Most importantly, research has clearly shown that this is not due to an achievement gap between sexes – this is a loss of highly talented female students who demonstrate the potential to excel at engineering and physics. Until this gender imbalance in high school physics courses is understood and rectified, the undergraduate engineering and physics programs in Ontario as well as the engineering profession will not reach their full potential.

Key Findings

Through careful analysis, several conclusions have been reached:

1. **High School represents our best opportunity to get greater numbers of women in engineering and physics.** The largest loss of potential women in engineering and physics careers occurs in high school. The majority of female students do not take the necessary curriculum courses required for application to engineering or physics university programs.

2. **A paucity of female students in high school physics.** 34% of all Ontario students enrolled in Grade 12 University Physics are female; this is the lowest participation rate of women in any Science, Technology, Engineering, and Mathematics (STEM) discipline. This translates into a 20% participation rate of women in undergraduate engineering and physics programs across Ontario.

3. **Higher level mathematics is not causing the gender gap.** Grade 12 Advanced Functions has a female participation rate of 47% while Grade 12 Calculus and Vectors is 44% female.

4. **There is not an achievement gap between the sexes.** Research has shown that both male and female students have equal aptitude in the fields of engineering and physics. A significant segment of the talent pool is lost strictly to the gender gap.

1 Background

1.1 The Leaky Pipeline

The "leaky pipeline" metaphor is often used to describe the continuous loss of women at all stages of a STEM career. Despite a steady increase in the representation of women at all levels in STEM, engineering and physics still have glaring gender deficits [1]. Women make up more than half of the Canadian population but across Canada today, fewer than 13% of practicing licensed engineers are women [2]. Similarly, fewer than 20% of undergraduate students in engineering and physics in Ontario are female. This stands in stark contrast with other STEM fields such as chemistry and biology where the participation of women is now on par with men [1]. It also highlights the need to examine engineering and physics separately from STEM in general.

The leaky pipeline in Ontario, see Fig. 1, illustrates the fact that the largest leaks occur during the high school years. Thus, to close the gender gap in undergraduate engineering and physics enrollment, the gender gap in high school physics must first be better understood.

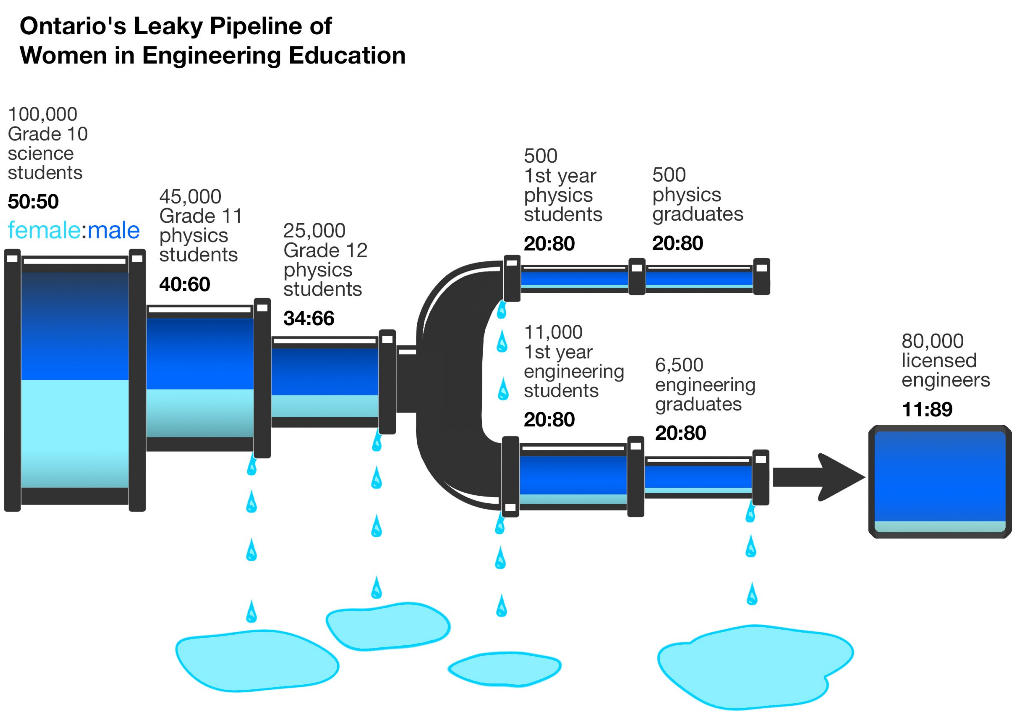

Figure 1: Ontario's Leaky Pipeline for Women in Engineering and Physics. The ratios are presented as the proportion of females:males at different points in the pipeline. Developed using Ontario Ministry of Education Enrolment data from 2016

1.2 Ontario High School Enrollment Rates

"Engineering and Physics Ready" refers to students who have taken all the required pre-requisite high school science and math courses for admission to undergraduate engineering or physics programs across Ontario. These courses include:

- Grade 12 English (ENG4U)
- Grade 12 Chemistry (SCH4U)
- Grade 12 Advanced Functions (MHF4U)
- Grade 12 Calculus and Vectors (MCV4U)
- Grade 12 Physics (SPH4U)

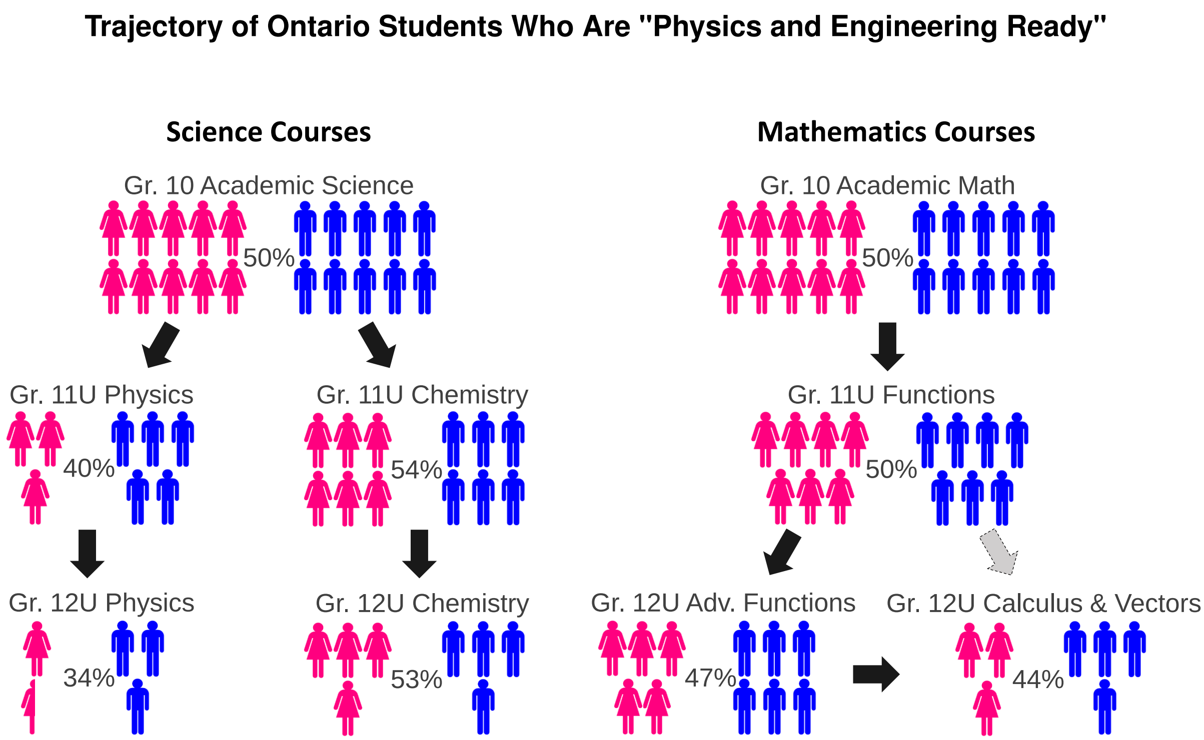

Figure 2: The trajectory of Ontario grade 10 students who become "Engineering and Physics Ready" by taking the required science and math courses. The figures illustrate the proportion of male and female students enrolled in higher level math and science courses relative to grade 10 academic courses. Figures are approximate and rounded to the nearest 5% of grade 10 participation. The percentages listed refer to the rate of female participation in each course. The shaded grey arrow indicates the fact that Calculus and Vectors can be taken as a co-requisite with Advanced Functions. Note, although Grade 12 English (ENG4U) is required to be "Engineering and Physics Ready", it is not included here as it is a mandatory course for all students unlike SPH4U, SCH4U, MHF4U, and MCV4U.

Fig. 2 clearly shows that physics has the lowest number of students and greatest gender imbalance of all STEM courses required to make students "Engineering and Physics Ready". From Grade 10 Academic Science (the most senior mandatory science course in Ontario) through to Grade 12 Physics, there is a loss of $\sim 70\%$ of male students and $\sim 85\%$ of female students.

Physics is often considered secondary to other STEM disciplines, but the way it is taught has a significant impact. In K-8, almost half of the science and technology curriculum is composed of topics traditionally associated with physics [3]. Further, any students who are "Engineering and Physics Ready" will automatically meet and surpass the university entrance requirements for all other STEM disciplines in Ontario. Therefore, ensuring that more students become "Engineering and Physics Ready" can positively improve enrollments in all STEM disciplines. Most importantly, Grade 12 Physics is required for application to all undergraduate engineering and physics programs across Ontario. This has serious implications with respect to the talent pool of incoming students. These negative effects then extend well beyond undergraduate programs, adversely affecting our ability to produce a diverse and talented workforce – slowing innovation and economic development within the province [4].

To address this issue, some Canadian universities are actively considering the removal of Grade 12 Physics as an admission requirement for engineering programs. However, this just postpones the problem as students are then required to take a non-credit replacement course during their first year of university. A more informed approach would be to work with the Ontario Ministry of Education, high school science teachers, and guidance counselors to identify the reasons for the extremely low and gender skewed enrollment in Grade 12 Physics. This information can then be used to design and implement effective intervention programs to correct this problem.

2 Factors for Underrepresentation

Several potential factors have been suggested as explanations for the under-representation of females in the physics classroom. These can be broken up into three broad categories, adapted from the work of Hazari and Potvin: *Inherent Differences*, *Sociocultural Influence*, and the *Culture of Engineering and Physics* [5]. The research on each of these categories is briefly summarized below.

Inherent Differences: Inherent differences refers to the possibility that fundamental differences between male and female students, e.g. biological characteristics or psychological traits, are to blame for the under-representation of women in engineering and physics. Research has shown that males and females do understand physics differently. The research suggests that male students are satisfied understanding physics on a technical level while female students prefer to understand physics within the context of a broader world view [6]. However, further research has found that females perform equally well (if not slightly better) on standardized tests of both physics and science at the age of 16 [7]. Thus, both male and female high school students have an equal aptitude for physics even though they understand the subject differently. Having more women working as engineers and physicists will then add to the diversity of thought and promote innovation [8].

Sociocultural Influence: Sociocultural Influence refers to societal attitudes about what is considered appropriate for girls and women. Sociocultural factors such as parental or teacher interactions, self-confidence, and interest in the fields of engineering and physics can affect students in several ways. Adults systematically rate girls as less academically capable and less likely to enjoy science - even when controlling for differences in performance and interest [9]. This leads to parents providing less encouragement and support for girls studying physics compared with boys [7]. Teacher interactions also affect students' desires to continue studying physics [10] and the development of female students' physics identity [11]. Physics identity refers to a student's ability to see themselves as a physicist and the belief that they are capable of understanding and doing physics. The development of a physics identity has been shown to be a strong predictor of future engineering and physics work [11]. The role of the broader community also plays a significant role. Girls who grow up in a community with a large proportion of women working in STEM careers have higher female enrollment rates in high school physics [12].

Culture of Engineering and Physics: This refers to the culture within the engineering and physics disciplines and how this is presented to students. For example, teaching materials, textbooks, and lectures tend to depict science and technology, especially physics, as a male domain. Depriving girls of role models contribute to the idea that women don't belong in engineering and physics. This barrier is to some extent exacerbated by the narrow technological focus of the curriculum. While appealing to many boys, a focus only on technical details can alienate girls who are more interested in understanding how engineering and physics fit into a larger social, environmental or work context [6]. Girls further benefit from science and technology teaching curricula that emphasize hands-on activities and application to everyday life, ensuring the subject feels more personally relevant [13]. The preconception that scientists are objective and distanced observers of their world promotes a view of science that removes people and human struggle from the inquiry. This can alienate individuals for whom their relationships with teachers and friends are important parts of their educational experience, including many female students [11]. Shifting to a broader worldview of engineering and physics is likely to attract more girls, as well as boys alienated by the current system, producing better engineers and physicists.

Summary: Overall, the field has a broad understanding of why girls are not attracted to STEM fields. However, the current literature is based largely on qualitative studies, small sample sizes, or a focus on STEM as a whole. Further, the current literature primarily focuses on an abstract understanding of these issues. The design, implementation, and testing of concrete intervention techniques are almost non-existent in the research community. As discussed earlier, it is clear that engineering and physics need to be treated independently if we are to understand and fix this issue. Working directly with the Ministry of Education and School Boards would allow access to a large and quantitatively meaningful data set about student enrollment and achievement.

3 Conclusions

There is a need for a concerted and co-ordinated effort to understand the root causes leading to the lower female participation in engineering and physics. A key to closing the gender gap in Ontario engineering and physics programs as well as the engineering profession, requires a critical examination of the current Ontario education system. Specifically, there needs to be a greater understanding of why so few students, especially women, enroll in advanced physics courses within the Ontario high school system. The research summarized here strongly suggests that the gender gap in engineering and physics is primarily driven by social factors and not biological differences – but further examination is necessary to alleviate this problem. We are proposing the following short and long term recommendations for the Ministry of Education to help mitigate the gender imbalance:

1. Create public awareness of the gender imbalance in physics classrooms, its implication on Canadian society, and make a public commitment to address and support K-12 education to repair the leaky pipeline.
2. Revitalize K-12 classroom programs to reflect the current and future realities of Science, Technology, Computer Science, and Mathematics curriculum areas, ensuring that students are Engineering and Physics ready.
3. Provide training for K-12 educators to create STEM programs that are societally relevant with intentional learning outcomes to build skills and a deep understanding of physics concepts.
4. Develop research partnerships between the Ministry of Education, Post-Secondary Institutions, and School Boards to ensure that intervention strategies are measured for impact and outcomes are documented for ongoing work.

Through an effective research and intervention based partnership with the Ministry of Education, we are confident that many of the barriers preventing talented women from participating in engineering and physics can be mitigated. This will produce a talented and diverse workforce in all STEM related fields, increasing economic productivity, and enabling Ontario to remain innovative and competitive in a rapidly developing world.

Endorsements

This white paper has been endorsed by a number of organizations and associations across Ontario and Canada. This reflects the importance of this topic throughout the professional and academic communities.

Sandro Perruzza, CEO – Ontario Society of Professional Engineers

Dr. Bruce Gaulin, President – Canadian Association of Physicists

Chris Meyer, President – Ontario Association of Physics Teachers

Annette Bergeron, MBA, FCAE, FEC, P.Eng., President – Engineers Canada

Mark Abbott, Executive Director – Engineering Change Lab

Dr. Kim Jones, Chair – Ontario Network of Women in Engineering

Council of Ontario Deans of Engineering

Dr. Ishwar Puri, Chair – Council of Ontario Deans of Engineering

References

[1] Integrated Postsecondary Education Data System and American Physical Society. Bachelor's degrees earned by women, by major. https://www.aps.org/programs/education/statistics /womenmajors.cfm. 2018.

[2] Engineers Canada. National membership report. https://engineerscanada.ca/reports/national -membership-report/2018-report. 2018.

[3] Ontario Ministry of Education. Ontario curriculum grades 1–8: Science and technology. 2007.

[4] H. Hunt, S. Prince, S. Dixon-Fyle, and L. Yee. Delivering through diversity. *McKinsey Company*, 2018.

[5] Z. Hazari and G. Potvin. Views on female under-representation in physics: Retraining women or reinventing physics? *European Journal of Science Education*, 10(1):1–33, 2006.

[6] H. Stadler, R. Duit, and G Benke. Do boys and girls understand physics differently? *Physics Education*, 35(6):417, 2000.

[7] T. Mujtaba and M. Reiss. What sort of girl wants to study physics after the age of 16? findings from a large-scale uk survey. *International Journal of Science Education*, 35(17):2979–2998, 2013.

[8] K. W. Phillips. How diversity makes us smarter. *Scientific American*, 2014.

[9] C. Newall, K. Gonsalkorale, E. Walker, G.A. Forbes, K. Highfield, and N." Sweller. Science education: Adult biases because of the child's gender and gender stereotypicality. *Contemporary Educational Psychology*, 55:30 – 41, 2018.

[10] M. Oliver, A. Woods-McConney, D. Maor, and A. McConney. Female senior secondary physics students' engagement in science: a qualitative study of constructive influences. *International Journal of STEM Education*, 4(1):4, 2017.

[11] Z. Hazari, E. Brewe, R. M. Goertzen, and T. Hodapp. The importance of high school physics teachers for female students' physics identity and persistence. *The Physics Teacher*, 55(2):96–99, 2017.

[12] C. Riegle-Crumb and C. Moore. The gender gap in high school physics: Considering the context of local communities. *Social Science Quarterly*, 95(1):253–268.

[13] K.M. Stokking. Predicting the choice of physics in secondary education. *International Journal of Science Education*, 22(12):1261–1283, 2000.