Engaging more women and girls in mathematics and STEM fields: The international evidence

Report prepared for the Australian Mathematical Sciences Institute

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May 2014

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Executive summary

Women are under represented in Science, Technology, Engineering and Mathematics (STEM) fields in education and employment, with gender disparity particularly apparent in disciplines such as mathematics, engineering and computing. This claim is well supported by the data. Only 28% of the employed STEM-qualified Australians aged 15 years and over were female in 2011, with this figure as low as 14% in the field of engineering. In the same year, only 33% of tertiary qualifications were awarded to Australian women in STEM fields. Poor participation of girls in mathematics is particularly troubling, as this is a gateway discipline to other fields. It is not only advantageous to have studied intermediate or advanced level mathematics at secondary school, but in many cases it is requisite to tertiary study in STEM disciplines, such as engineering and computing. Nonetheless, only 6.6% of all female year 12 students in Australia in 2013 studied an advanced level mathematics subject, while 17.5% took intermediate level mathematics in the same year. While participation rates in advanced mathematics are low across the board, both of these figures are lower than for their male peers.

There are a myriad of causes that contribute to the under representation of women in STEM fields. These include cultural stereotypes and ignorance of what these careers entail, as well as a lack of encouragement from teachers and parents. There are also a number of reasons it is important that this issue be addressed. In particular, there is an economic imperative to strengthen innovation and maximize productivity through the encouragement of women to stay on into STEM careers. Furthermore, there are concerns about the quality of research, labour market balance and social justice considerations effecting the common good.

The search for effective measures to address the under representation of women in mathematics and other STEM fields has always been unchartered. The causes are deeply ingrained and intertwined with historical and cultural norms. What has become clear is that there is no silver bullet. That is, no one measure will effectively reverse the problem. Also, there is no comparable country or system that can be heralded for being wholly successful in implementing any particular suite of measures and seeing their national level of female participation respond. That is not to say that progress has not been made elsewhere. Indeed, there are many examples of implemented programs and measures that can be cited as effective across the range of levers available. However, the consistency and extent of national effort required to turn around women's participation rates in mathematics and other STEM disciplines across a system is a challenge yet to be met.

In this report, evidence of effective measures has been identified in the literature and is provided within 7 categories: Government led measures; Financial incentives; Direct support programs; Community development; School based measures; Industry or employer led measures; and Combining approaches to produce

government led consistency. In this final section, two examples are provided of the most coordinated national efforts to improve women's engagement in STEM. These are important examples are the most impactful changes must be diverse and gain broad support, if we are to effectively address the under representation of women in STEM disciplines in a sustainable way.

A persistent problem

Under representation of women in STEM fields

Women are under represented in science, technology, engineering and mathematics (STEM) fields in numerous ways throughout their education and career. Gender disparity among those employed in STEM fields in Australia is significant. Among the STEM-qualified population aged 15 years and over, 72% of those employed in 2011 were male, while only 28% were female[1]. The divergence is most acute in the fields of Information Technology and Engineering, where the proportion of women employed is as low as 25% and 14% respectively[2]. These figures compare to the overall Australian tertiary qualified population aged 15 years and over, in which women accounted for 55% of those employed in 2011[3]. The gender disparity in the STEM workforce is not only apparent in Australia; a similar picture can be seen internationally. For example, women accounted for only 24% of the STEM workforce in the United States in 2009, a proportion unchanged since 2000[4]. In the sciences, where the best international comparative data is collated, the picture appears slightly different. The European Union records the proportion of women in the labour force in science and technology fields at 46.5% in 2012[5]. Similarly, women made up around 35% of science-related tertiary graduates among 25-34 year-olds in employment in OECD countries in 2010[6].

Gender disparity in STEM fields is not isolated to the labour market, but can be traced back through each level of education. The under representation of women has been termed a leaky pipeline, in reference to the increasing loss of women from STEM fields through education and employment. In education, gender based disparity has been masked by growing numbers of female students enrolling in, and graduating from, universities, and increasing absolute numbers of enrolments in the fields of science and technology. However, at the tertiary level, the evidence for a gender based disciplinary divergence in participation is clear. Men outnumber women in mathematics, statistics, sciences (particularly physics), engineering, manufacturing, construction and computing, while women outnumber men in the study of health, welfare, education, humanities, arts, agriculture, life sciences, services, social

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[1] Healy, J., Mavromaras, K. and Zhu, R. (2013) *The STEM Labour Market in Australia*. Contributing consultant report to 'STEM: Country Comparisons' project. National Institute of Labour Studies, Flinders University, on behalf of ACOLA. Australian Office for the Chief Scientist: Canberra. Available online, http://www.acola.org.au/PDF/SAF02Consultants/Consultant%20Report%20-%20Australian%20Labour%20Market.pdf
[2] Healy *et al*., 2013
[3] Healy *et al*., 2013
[4] US Department of Commerce, Economics and Statistics Administration (2011) *Women in STEM: A Gender Gap to Innovation*, Author: Washington D.C.
[5] Eurostat (2014) *Human Resources in Science and Technology as a Share of Labour Force – Total*. Available online, http://open-data.europa.eu/en/data
[6] OECD (2012) *Education at a Glance: OECD Indicators*. OECD Publishing: Paris.

sciences, business and law[7]. The most recent OECD data reveal that only just over 30% of tertiary qualifications were awarded to women in STEM fields in OECD countries in 2011[8]. The qualifications were awarded to the smaller proportion of women (20%) in computing, and highest in the life sciences (54%). These figures remain little changed from the year 2000, when just over 31% of tertiary qualifications were awarded to women in STEM fields. The range also remains steady, with the lowest figure in 2000 found in engineering (21%) and the highest also in the life sciences (55%). In Australia, completion is slightly lower than the OECD average. In 2011, 33% of tertiary qualifications were awarded to women in STEM fields, with this number essentially unchanged from 32% of Australian women in 2000[9].

Secondary level education reveals a similar picture of participation in STEM subjects. For example, in New South Wales in 2011, only 18.6% of boys continued STEM subjects into their final year, compared with only 13.8% of girls[10]. Disciplinary gender divergence is also apparent, with girls tending to choose biology or psychology in preference to physics or chemistry, and tending to choose either basic or intermediate level mathematics over advanced level subjects. At 15 years of age, the career ambitions of male and female students have already shaped their STEM engagement. In addition to testing students' level of mathematical and scientific literacy, the OECD's Programme for International Student Assessment (PISA) surveys 15 year-old students, collecting a range of data, including their expectations of science careers[11]. The 2006 round of international testing found that in Australia, as many as 28.7% of the female and 27% of the male participants reported an expectation of being in a science-related career by 30 years of age. This is comparatively higher than the OECD average figures, especially for males. However, when the data are divided into two discipline-based categories – computer sciences and engineering, and health sciences and nursing – the gendered distribution becomes more distinct. The most striking difference illustrated here is in student expectations of careers in computer sciences and engineering. As many as 46% of the boys tested in PISA 2006 indicated an expectation of a career in one of these fields, compared with only 8% of girls, which highlights a slightly greater divergence between genders than is exhibited internationally through the OECD average. Of the countries shown in Figure 18, Australia has the lowest number of 15 year-old girls expecting careers in health sciences and nursing at 64%, while close to the average number of boys (22%)

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[7] Education at a Glance 2013; Bell (2010) "Women in science: The persistence of gender in Australia." *Higher Education Management and Policy*. OECD Publishing. 22(1):1-19.

[8] Note: These qualifications include both tertiary type A and advanced research programs, accounting for Bachelor degrees, Masters degrees and doctoral research.

[9] OECD (2013) *Education at a Glance 2013: OECD Indicators*. OECD Publishing: Paris.

[10] Marginson, S.M., Tytler, R., Freeman, B. and Roberts, K. (2013) *STEM: Country comparisons*. Report for PMSEIC and the Office for the Chief Scientist. ACOLA, Melbourne. Available online, http://www.acola.org.au/PDF/SAF02Consultants/SAF02_STEM_%20FINAL.pdf

[11] OECD (2010) 'Expectations for science-related careers by gender'. *OECD Factbook 2010: Economic, Environmental and Social Statistics*. OECD Publishing: Paris.

expect careers in these fields. Again, a predictable pattern of gender disparity. A study of secondary participation in sciences in Australian education found that this is, indeed, a critical factor in determining engagement in tertiary level science courses. This research found that almost three quarters (74%) of students who studied two science subjects in their final year of secondary school continued on to study science-related areas at university[12].

The data highlight a disciplinary pattern of gendered participation in Australia, though similar patterns can be observed internationally. Tertiary completion data from Finland reveals that while around 60% of all completions from Bachelor through to doctoral researchers are women, in the field of engineering this figure is only 25% of graduates[13]. National figures at upper secondary reveal the beginnings of this pattern. In 2011, women represented 66% of all Finnish year 12 candidates taking biology, 55% of those taking basic mathematics, while accounting for only 44% of those who took an advanced level mathematics course. For reference, nearly 59% of all year 12 candidates in the same year were female[14]. A similar pattern of discipline based under representation is apparent in Russia. The most recent figures reveal that only 35% of national enrolments in Bachelor or Masters level programs in physics and mathematics are women. However, science participation among Russian women is high standing at 64% of enrolments[15]. Across Western Europe between 15% and 35% of male tertiary graduates undertook STEM studies. The comparable range for women is between 5% and 15%. Importantly, women account for a small proportion of all engineering graduates in Europe, ranging from just over 30% in Latvia to around 8% in the United Kingdom[16]. Secondary school participation in France highlights well established ambition and achievement levels for young women in the country. However, their participation by discipline reveals an ongoing gender gap. Females account for 58% of the upper secondary students in general academically oriented programs choosing the life and earth sciences study track, 47% of those choosing

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[12] Ainley, J., Kos, J. and Nicholas, M. (2008) *Participation in science, mathematics and technology in Australian education*. ACER Research Monograph No. 63. Australian Council for Educational Research, Ltd.: Camberwell.

[13] Dobson, I.R. (2013) A Critical Examination of Existing Solutions to the STEM Skills Shortage in Comparable [European] Countries. Country Report: Finland. Contributing consultant report to 'STEM: Country Comparisons' project. On behalf of ACOLA, for the Australian Office for the Chief Scientist: Canberra. Available online, http://www.acola.org.au/PDF/SAF02Consultants/Consultant%20Report%20-%20Finland.pdf

[14] *ibid*.

[15] Smolentseva, A. (2013) *Science, Technology, Engineering and Mathematics: Issues of Educational Policy in Russia*. Contributing consultant report to 'STEM: Country Comparisons' project. On behalf of ACOLA, for the Australian Office for the Chief Scientist: Canberra. Available online, http://www.acola.org.au/PDF/SAF02Consultants/Consultant%20Report%20-%20Russia.pdf

[16] Dobson, I.R. (2013) *Europe A critical examination of existing solutions to the STEM skills shortage in comparable countries – Western Europe*. Contributing consultant report to 'STEM: Country Comparisons' project. On behalf of ACOLA, for the Australian Office for the Chief Scientist: Canberra. Available online, http://www.acola.org.au/PDF/SAF02Consultants/Consultant%20Report%20-%20Western%20Europe.pdf

physics and chemistry, 40% of those in mathematics and only 14% of all those choosing engineering[17].

The under representation of women in science and other STEM fields is thought to be a problem for a number of reasons. Five arguments are posed in the literature[18]. However, the last of these is most emphasized and widely asserted. The first argument is for better concordance of the STEM labour force with the population. When the gender balance is aligned with the real world, it is more likely that the research will, accordingly, be better aligned, and so more productive and relevant to the real world applications of the work. Another argument for including women is to boost the quality of STEM research. Diversity of participation enables greater creativity and reduces potential bias, both of which improve research quality. The third argument found in the literature for gender equality is in pursuit of social justice, fairness and human rights. If all people are equal, then all should be able to experience equal opportunity, including the circumstances that enable them to engage successfully in STEM education and careers. Another argument cites concerns for the common good. Research attempts primarily to address the common needs and issues facing the population and is financed by common funds, such as tax revenues. It, therefore, makes sense to involve all sub groups of the population.

The most widely asserted argument for the importance of reaching gender balance in STEM fields is based upon economics. The economic imperative drives much of the international debate on STEM enhancement, with concerns for human capital, innovation and productivity at the forefront of this strategy[19]. The need to improve participation and performance in STEM fields is often considered of concern due to its economic impact. Words are used in policy documents such as *strategic importance to national economic growth*, or *international competitiveness through innovation*, or *maximizing productivity*. The need to improve the situation for women specifically is often motivated by concern for women as an under utilized resource that has the potential to boost the labour force in this sector and provide a larger talent pool within which to search for the best and brightest. Furthermore, the human capital of those women who have undertaken training in one of these fields and left their career prematurely has not been effectively maximized.

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[17] de Oliveira, E. and Roberts, K. (2013) *Literature Review: STEM Education in France*. Contributing consultant report to 'STEM: Country Comparisons' project. On behalf of ACOLA, for the Australian Office for the Chief Scientist: Canberra. Available online, http://www.acola.org.au/PDF/SAF02Consultants/Consultant%20Report%20-%20France.pdf

[18] Roberts, K. (2013) *Literature Review – A Selection of the Work of International Organizations on STEM education and STEM-related issues*. Contributing consultant report to 'STEM: Country Comparisons' project. On behalf of ACOLA, for the Australian Office for the Chief Scientist: Canberra. Available online, http://www.acola.org.au/PDF/SAF02Consultants/Consultant%20Report%20-%20International%20agencies.pdf

[19] *ibid*.

A gateway discipline: Mathematics in trouble

The need to address the persistently low female engagement across STEM fields has become urgent. As a gateway discipline, the poor participation of girls in mathematics is both particularly troubling, and an opportunity for perhaps the most substantial impact. It is not only advantageous to have studied intermediate or advanced level mathematics at secondary school, but in many cases it is requisite to tertiary study in STEM disciplines, such as engineering, computer sciences and physics – key disciplines and vocations in which females are significantly under represented. In a sense, mathematics can be empowering, as skills in mathematics are "considered essential to success in STEM fields"[20].

The gender based disciplinary divergence in participation rates at the tertiary level is particularly problematic for women in mathematics and its related disciplines, such as statistics, engineering and computing. In Australia in 2011, only 39% of tertiary type A and advanced research qualifications were awarded to women in the fields of mathematics and statistics, up only 2% since 2000[21]. Although women are poorly represented in these disciplines internationally, the Australian figures were well under the OECD averages of 42% in 2000 and 45% in 2011. Representation is even lower in engineering and computing – degree programs that require both high school advanced mathematics to enter and that usually contain a significant mathematics component themselves. In fact, in 2011, only 25% of the tertiary type A and advanced research qualifications were awarded to Australian women in engineering, manufacturing and construction, with only 20% in computing[22]. Indeed, at Bachelor level, young women in Australia account for about 14% of accepted university engineering places[23]. Even so, a greater proportion of the employed female engineers in Australia are recent graduates, while male engineers tend to have graduated prior to 1985[24].

Internationally, there is a similarly acute under representation of women within mathematics-rich STEM disciplines. In the United States, women accounted for only 14% of the STEM workforce in 2009. Within computer sciences and mathematics, 27% of those employed in 2009 were women, down from 30% in the year 2000[25]. In Canada, women account for more than half of the tertiary students in all areas except for these three fields, plus architecture. While 44% of all doctoral graduates in Canada were women in 2008, these students predominantly studied in education, social science, law and health. The average was brought down in part by

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[20] Hill, C., Corbett, C. and St. Rose, A. (2010) *Why So Few? Women in Science, Technology, Engineering and Mathematics*. American Association of University Women: Washington, D.C., p.3.
[21] OECD (2013) *Education at a Glance 2013: OECD Indicators*. OECD Publishing: Paris.
[22] *ibid*.
[23] Andre Kaspura (2012) *Women in Engineering: A Statistical Update*. Engineers Australia: Canberra.
[24] Andre Kaspura (2012) *The Engineers Australia Survey of Working Environment and Engineering Careers*. Engineers Australia: Canberra.
[25] US Department of Commerce, Economics and Statistics Administration (2011) *Women in STEM: A Gender Gap to Innovation*, Author: Washington D.C.

the fields of agriculture, natural resources, physics, life sciences, technology and humanities, and most dramatically by mathematics, computer science, architecture, engineering and related technologies. Only 10% of enrolments in computer engineering in Canada between 1991 and 2007 were women, 23% of civil engineering students and nearly 40% of those enrolled in undergraduate programs in biosystems, chemical or environmental engineering. This division between sub-disciplines of engineering is also apparent in Portugal. Females represent 60% of tertiary level biomedical engineering students, 25% of civil engineering, and only 10% of those in electrical, computer, mechanical and industrial engineering fields. In the European Union, the picture is again similar. The proportion of all female tertiary graduations from the STEM fields is low. In 2011, only 6.4% of female graduates have completed science, mathematics or computing qualifications. Furthermore, in the same year, less than 1% of female graduates completed mathematics or statistics across the European Union, and 2.5% completed engineering or trade programs. This is in contrast to an area like business, which is far more popular with women, attracting more than 15% of female tertiary students in Europe.

Secondary school level mathematics is where students choose to be able to go on to further study in mathematics and its associated disciplines. These fields at tertiary level rely on, and indeed require, engagement in both intermediate and advanced level mathematics subjects during years 11 and 12. Across Australia, female participation in these subjects has been poor, with the proportion of girls taking these subjects even falling in recent years. In fact, only 47.3% of students studying intermediate or advanced mathematics programs at year 12 level were girls in 2000. By 2004, this proportion had already fallen to 45.6%[26]. Another way to understand the problem is to look at the proportion of all female year 12 students who choose to take advanced level mathematics. Across Australia, around 76% of girls took a mathematics subject in year 12, compared with 85% of boys[27]. Approximately equal numbers were enrolled in an elementary mathematics subject. However, only 6.6% of all female year 12 students in 2013 studied an advanced level mathematics subject, down from 7.7% in 2006[28]. This is in contrast to 12.6% of male year 12 students in 2013 and 13.9% of male students in 2006. Predictably, intermediate level mathematics subjects are far more popular, though not as much as elementary level courses. On average across Australia, 17.5% of female year 12 students took intermediate level mathematics in 2013, down from 20.2% in 2006[29]. For comparison, 20.6% of male year 12 students in 2013 and 23.4% of male students in 2006. In each jurisdiction, all students who take advanced level mathematics, also take the intermediate subject. In this case, the figures refer to those who take only intermediate as their highest level.

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[26] Andre Kaspura (2012) *Women in Engineering: A Statistical Update*. Engineers Australia: Canberra.
[27] Data collected and disseminated by the Australian Mathematical Sciences Institute.
[28] *ibid*.
[29] *ibid*.

There are a myriad of factors that contribute to the under representation of women in mathematics and other STEM fields in education and employment. These include the nature and organization of STEM fields of study and employment, exclusion from funding and other decision making bodies, the impenetrability of existing disciplinary networks, as well as a lack of counter measures and policies within national systems[30]. The balance between work and family demands, and the extent to which this is accommodated within the workplace is also problematic for young women. Importantly, there are also important social factors, ideas held by parents, teachers and others within the community that impact female engagement in mathematics and other STEM fields. These social factors include:

- Stereotypical viewpoints about the nature of STEM careers. These stereotypes are often fuelled by ignorance and create significant disincentive for girls and women to become interested in and pursue study and careers in particular STEM fields.
- Traditional associations of particular careers or areas of excellence with *masculine* and *feminine*[31]. This particular type of stereotyping associates mathematics, engineering and other STEM fields with masculine, while other pursuits are considered feminine – including the life sciences, teaching and nursing. These views translate directly into levels of participation.
- Negative perceptions of particular career types held by young women, whether grounded in fact or not. Many women dislike the idea of occupations that require construction, heavy lifting or outdoor work, preferring instead interaction with people, or working in clean, perhaps office-like environments.
- Poor direction from parents and teachers can also play a role. While at school, when a students' interest is generated by mathematics or science related learning, there is often a gendered bias towards male students being encouraged to translate this interest into study or career ambition. These influences are often small, or subliminal, but are nonetheless real.
- The lack of women in STEM study and careers has created a small pool of women to act as role models. This includes both high school teachers and industry professionals. Poor visibility of successful women can be detrimental to encouraging young women to choose STEM paths.

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[30] Roberts, K. (2013) *Literature Review – A Selection of the Work of International Organizations on STEM education and STEM-related issues*. Contributing consultant report to 'STEM: Country Comparisons' project. On behalf of ACOLA, for the Australian Office for the Chief Scientist: Canberra. Available online, http://www.acola.org.au/PDF/SAF02Consultants/Consultant%20Report%20-%20International%20agencies.pdf

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

Finding effective measures

The search for effective measures to address the under representation of women in mathematics and other STEM fields has always been unchartered. The causes are deeply ingrained and intertwined with historical and cultural norms. What has become clear is that there is no silver bullet. That is, no one measure will effectively reverse the problem. Furthermore, isolated efforts have the potential only to reap isolated success. The literature consistently reveals that initiatives solely confined to any one area, case or set of goals will not be able to redress the gender imbalance overall. Instead, measureable and sustainable increases in female engagement require a consistent and concerted effort which pulls a little on all the levers available.

Also critically important to the search for effective measures is the fact that there is no comparable country or system that can be heralded for being wholly successful in implementing any particular suite of measures and seeing their national level of female participation respond. That is not to say that progress has not been made elsewhere. Indeed, there are many examples of implemented programs and measures that can be cited as effective across the range of levers available. However, the consistency and extent of national effort required to turn around women's participation rates in mathematics and other STEM disciplines across a system is a challenge yet to be met.

Despite these warnings against complacency and simplification, the remainder of this review will be dedicated to identifying the variety of measures that have found success or recommendation through research. These potentially effective measures include those available to improve female participation in both study and employment within mathematics and other STEM fields. These measures are presented across six categories: government led measures, financial incentives, direct support programs, school based measures, industry or employer led measures, and community development.

Government led measures

Governments of all levels have the potential to influence the gender balance across STEM fields of study and work. Their influence on education is of course profound at State and Federal levels, but there are also important ways in which they have the ability to provide conditions and incentives to improve the gender balance in the work place. The potential actions of government include consistency in the national policy agenda, legislation against discrimination, engagement in the making of directed policy, quotas and targets, the activation of government agencies and other professional bodies or associations, and in the collection of consistent and informative data on gender outcomes within STEM fields.

Creating a consistent national policy agenda is known as gender mainstreaming. This strategy is proposed in the European literature[32] and by UNESCO[33]. In essence it refers to the systemic commitment to gender equality in STEM education and careers, through a combination of elements, including political will, legislation, greater understanding of gender issues, mandated involvement of women on decision-making bodies and to senior appointments, more appropriate human resource processes and funding systems. This type of policy agenda must include a clear and sincere commitment from policy makers, scientific and leaders in other STEM fields, as well as a consistent effort through time to maintain the focus.

Governments also have a significant legislative role to play. In France, the National Ministry of Education made it a priority to steer the career ambitions of more young women towards the STEM fields. Equality legislation was therefore enacted to encourage the diversification of girls' professional choices. Equality legislation must extend to top-level appointments in academia or positions on decision making bodies, such as research councils, is an important strategy. Important elements of this include procedural transparency, standardized selection procedures, wide spread publishing of position advertisements, headhunting highly qualified women, and monitoring gender dis-aggregated data on selection and hiring outcomes. Norway is a good example of the success of this approach. At one Norwegian University, equality oriented searching was conducted through committees established for the identification and recruitment of qualified women. In Canada, the reverse is the case. The under representation of women in STEM has not been a significant part of federal policy thinking or reports on STEM fields in recent years. Women in Canada are particularly under represented in STEM fields and the country has experienced little improvement in recent years.

Engagement of women in policy processes, funding and human resource decisions has also been shown to improve participation. For example, the EU imposed a target on expert group and committee membership. Since the mid 2000s, all decision making boards were required to be composed of at least 40% of each sex. The strategy has apparently successfully "led to a strong increase in the participation of women on evaluator panels for research proposals submitted"[34].

Targets and quotas are also important policy levers for governments. System-wide targets can be set in order to mandate the attainment of gender equity

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[32] European Communities (2008) *Mapping the Maze: Getting More Women to the Top in Research*. Scientific Culture and Gender Issues, Directorate of Science, Economy and Society. European Commission: Brussels. Document Number: EUR 23311 EN; European Communities (2004) *Europe Needs More Scientists*. Report of the High Level Groups on Human Resources for Science and Technology in Europe. Education and Science. Directorate of Science and Society. European Commission: Brussels.

[33] UNESCO (2007) *Science, Technology and Gender: An International Report*. Science and Technology for Development Series. UNESCO, Division for Science Policy and Sustainable Development.

[34] European Communities, 2008, p.10.

within mathematics and other STEM disciplines. Targets can be set for example for funding rates and the uptake of paternity leave, while quotas can stipulate the proportion of women in senior positions or as participants in decision making processes. The success of these types of measures compounds when implemented together[35]. An example is Finland, where targets and goals were arranged as part of equality plans in many universities. However, there was a distinct lack of systematic follow up or incentives based on achievement of these plans, and so their success was limited. Targets and quotas that mandate the inclusion of women are, of course, particularly direct means of achieving outcomes. Quotas are the most strict, as they require, rather than aim to achieve, a level of equality. But, the research community usually prefers to deal with targets. For example, in Japan, the 4th Science and Technology Basic Plan intends to increase numbers of women researchers in STEM fields, through targets for women's participation in science, engineering, agriculture and health university programs[36]. In Sweden, political pressure from policy makers to achieve targets is strong and has effectively increased the participation of women, whilst maintaining institutional autonomy in decision making and appointments.

It is important to make note of the potential downsides of targets and quotas including the perception of discrimination against men, the neglect of cultural elements of the issue, the imposition of equality that becomes unsustainable, rather than organically and culturally instilling the practice of equality. A statistical analysis of European data found a negative correlation between countries with targets or quotas for women in science and the actual number of women employed as researchers in this field[37]. It seems that these measures are not effective in general, not effective on their own, or simply not effective yet (perhaps they take more time to influence the overall culture of participation)[38]. Or even, the quotas may not be influencing the private sector, which normally exhibits the greatest inequality.

Governments have a key role in the collection of data, where is much room for improvement[39]. There is a need for more consistent data collection, informative and

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[35] Roberts, K. (2013) *Literature Review – A Selection of the Work of International Organizations on STEM education and STEM-related issues*. Contributing consultant report to 'STEM: Country Comparisons' project. On behalf of ACOLA, for the Australian Office for the Chief Scientist: Canberra. Available online, http://www.acola.org.au/PDF/SAF02Consultants/Consultant%20Report%20-%20International%20agencies.pdf

[36] Ishikawa, M. and Moehle, A. (2013) *STEM Country Comparisons: Japan*. Contributing consultant report to 'STEM: Country Comparisons' project. On behalf of ACOLA, for the Australian Office for the Chief Scientist: Canberra. Available online, http://www.acola.org.au/PDF/SAF02Consultants/Consultant%20Report%20-%20Japan.pdf

[37] European Communities (2008) *Mapping the Maze: Getting More Women to the Top in Research*. Scientific Culture and Gender Issues, Directorate of Science, Economy and Society. European Commission: Brussels. Document Number: EUR 23311 EN.

[38] *ibid*.

[39] Bell, S., O'Halloran, K. Saw, J. and Zhao, Y. (2009) *Women in Science in Australia: Maximizing productivity, diversity and innovation*. Federation of Australian Scientific and Technological Societies: Canberra.

gender dis-aggregated statistics, and clearer indicators related to women's participation in STEM fields of study and work[40]. Furthermore, international consistency and regularity of collection is also needed, and so there is a role for governments here in their engagement with international organizations. Better data would allow researchers and policy makers to improve their understanding of where the problems lie, and to monitor the progress of implemented strategies. It would be useful to have data recording the economic burden or direct financial loss of losing or not attracting women into STEM disciplines. Moreover, the improved accountability of policies and measures would be particularly productive. In the United States, reports have been commissioned in 2011 and 2012 by the Department's of Commerce and Education to gain a better understanding of the state of women in STEM fields through ensuring the collation and dissemination of relevant data for better transparency[41].

Financial incentives

Financial incentives, such as scholarships or fellowships specifically reserved for female students and researchers, are also appropriate measures to improve the engagement of women in STEM fields. These measures are tried and tested motivators for change that are recommended part of the arsenal to combat gender inequality in STEM fields. They have been found to be successful in, for example, increasing the proportion of women who make it through to professorial roles. Specific measures include targeted strategic reservation of funds for women to assist their study and establish themselves as researchers, or the allocation of greater points in funding selection processes to proposed projects with balanced gender.

In Switzerland, a successful program of financial incentives to combat gender inequality has been in operation since 2000. Universities are provided with greater national governments funds for the appointment of female professors. Measures, such as scholarships or fellowships specifically reserved for female students and researchers, have also been positively correlated with the proportion of women in professorial roles in European countries. Specific measures include targeted strategic reservation of funds for women to assist their study and establish themselves as researchers, or the allocation of greater points in funding selection processes to proposed projects with balanced gender. Greece is a good example, where projects receive 5% higher in their evaluations during funding selection processes for each

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[40] Roberts, K. (2013) *Literature Review – A Selection of the Work of International Organizations on STEM education and STEM-related issues*. Contributing consultant report to 'STEM: Country Comparisons' project. On behalf of ACOLA, for the Australian Office for the Chief Scientist: Canberra. Available online, http://www.acola.org.au/PDF/SAF02Consultants/Consultant%20Report%20-%20International%20agencies.pdf

[41] Executive Office of the President (2013) *Women and Girls in Science, Technology, Engineering and Math (STEM)*. Office of Science and Technology Policy: Washington D.C. Available online, http://www.whitehouse.gov/sites/default/files/microsites/ostp/stem_factsheet_2013_07232013.pdf

female researcher involved. Spain is another example, where 5 points are added to an overall score out of 100 awarded to projects directed by a woman or with more than the average proportion of women involved in the research group applying for funds[42]. Similarly, in France, there is a foundation that arranges contests of women in science to provide grant funding called the L'Oreal France Foundation[43].

Direct support programs

Teachers, parents and other elements of the cultural environment play a critical role in the interest and achievement of girls in science and mathematics, and young women in their pursuit of careers in mathematics and other STEM fields. These are important elements, as it is often the confidence and attitudinal factors that play the largest role in deterring girls from mathematics in early life. Direct supports enable the impact of negative stereotypes to be reduced, provide the opportunity for greater awareness of what STEM study and work entails, and improve the self-efficacy of young women in their study of mathematics and the sciences. Direct support can include mentoring programs, the identification of role models and programs supporting student access, as well as career and course counseling services.

There are many examples of success programs to support access to role models for young women to encourage their pursuit of STEM study and work. In France, a program called *Les Femmes En Maths* depicts successful professional women who took mathematics and science through their study and career, bringing this information to the young. Another program called *Pour le Science*, launched in 2006 in secondary schools by the municipality of Versailles, was specifically directed at female students and aimed to encourage them to take up scientific careers[44]. In Israel, students have the opportunity to engage in a Google Israel program called *Mind the Gap!*[45]. The program tackles gender disparity, introducing girls to STEM related study and work, hosting female students at Google offices, sponsoring visits to R&D laboratories, university classrooms and conferences. Importantly, an

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[42] Roberts, K. (2013) *Literature Review – A Selection of the Work of International Organizations on STEM education and STEM-related issues*. Contributing consultant report to 'STEM: Country Comparisons' project. On behalf of ACOLA, for the Australian Office for the Chief Scientist: Canberra. Available online, http://www.acola.org.au/PDF/SAF02Consultants/Consultant%20Report%20-%20International%20agencies.pdf

[43] de Oliveira, E. and Roberts, K. (2013) *Literature Review: STEM Education in France*. Contributing consultant report to 'STEM: Country Comparisons' project. On behalf of ACOLA, for the Australian Office for the Chief Scientist: Canberra. Available online, http://www.acola.org.au/PDF/SAF02Consultants/Consultant%20Report%20-%20France.pdf

[44] *ibid*.

[45] Drori, G.S. and Netivi, A. (2013) *STEM in Israel: The Educational Foundation of 'Start-Up Nation'*. Contributing consultant report to 'STEM: Country Comparisons' project. On behalf of ACOLA, for the Australian Office for the Chief Scientist: Canberra. Available online, http://www.acola.org.au/PDF/SAF02Consultants/Consultant%20Report%20-%20Israel.pdf

unprecedented 40% of the girls who participated in this program in 2011 went on to choose computer science as a major stream in upper secondary school[46].

The European Union has implemented a number of mentoring initiatives in recent years to support female engagement in STEM fields. The European Network of Mentoring Programmes engages women at different career points in mentoring activities in order to support women in academia and research with their career development[47]. Similarly, in Norway, linkages have been systematically established between professors and PhD or postdoctoral level women, with reported evaluations of this endeavour being positive. In Finland, a program known as TiNA undertook to provide mentoring and direct access for upper secondary girls to female tertiary students in electrical engineering. Groups of school girls regularly visited a university School of Engineering to engage with the older students in activities designed to teach basic electronics. The program was successful for a short time before funding for the program ran out[48].

Well informed career and course counseling, untainted by gender bias, has successfully improved female engagement in STEM. For example, a program in Germany called Go MINT!, sponsored and provided female-specific guidance for female pupils. (Note that MINT is German for STEM.) This program formed part of the National Pact of Women in STEM and was established in 2008[49]. The guidance attempted to raise the interest of female pupils in STEM subjects and provided assistance in their study decisions, even facilitating engagement with existing professionals in STEM fields for interested students.

Community development

The cultural context has an instrumental role in shaping the interest and achievement of girls in mathematics and the sciences. Perceptions of STEM studies and careers in the community are another avenue for the implementation of change

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[46] *ibid*.

[47] Roberts, K. (2013) *Literature Review – A Selection of the Work of International Organizations on STEM education and STEM-related issues*. Contributing consultant report to 'STEM: Country Comparisons' project. On behalf of ACOLA, for the Australian Office for the Chief Scientist: Canberra. Available online, http://www.acola.org.au/PDF/SAF02Consultants/Consultant%20Report%20-%20International%20agencies.pdf

[48] Dobson, I.R. (2013) *A Critical Examination of Existing Solutions to the STEM Skills Shortage in Comparable [European] Countries. Country Report: Finland*. Contributing consultant report to 'STEM: Country Comparisons' project. On behalf of ACOLA, for the Australian Office for the Chief Scientist: Canberra. Available online, http://www.acola.org.au/PDF/SAF02Consultants/Consultant%20Report%20-%20Finland.pdf

[49] Dobson, I.R. (2013) *Europe A critical examination of existing solutions to the STEM skills shortage in comparable countries – Western Europe*. Contributing consultant report to 'STEM: Country Comparisons' project. On behalf of ACOLA, for the Australian Office for the Chief Scientist: Canberra. Available online, http://www.acola.org.au/PDF/SAF02Consultants/Consultant%20Report%20-%20Western%20Europe.pdf

strategies. This may involve improving the image of these disciplines in the community, dispelling myths and combatting ignorance of what it actually means to study and work in these fields. Unfortunately, little has been done in this sphere beyond the school community.

A good example of an effort in Australia to influence community views, particularly those of parents, about their daughters career choices is a program from the 1980s known as *Maths Multiplies Your Choices*. The campaign aimed to influence girls aged 13-15 years to choose subjects that could lead to scientific and technical careers, which would hopefully lead to more women working in STEM occupations in the longer term. The Victorian state government instigated the campaign, which included school mail outs, television commercials, radio advertisements, and other press such as tram panels. A formal evaluation of the program revealed that it was indeed successful in producing 'significant attitudinal, perceptual and behavioural changes[50].

School based measures

Schools play a critically important role in shaping girls' experience of science and mathematics. Declining numbers of girls taking advanced level STEM subjects in upper secondary is troubling. School learning in mathematics and science subjects during the middle school years often contributes to student selection of STEM disciplines in upper secondary, shaping their pathways into tertiary study. School based measures to influence girls' engagement in these pathways include teachers' professional development, as well as gender sensitive curriculum and pedagogy. Researchers have identified gender differences in the preferred styles of study in mathematics and sciences. These differences can create a bias in attracting males and females into further STEM study.

In Finland, the Arithmetic, Science, Technology and e-Learning (ASTeL) program attempted to improve the gender sensitivity of the learning environment through the development of web-based science and technology learning resources for primary school students[51]. A professional development component introduced these resources to teachers. In Israel, another example of professional development, assists

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[50] McAnalley, K. (1991) 'Encouraging parents to stop pigeon-holing their daughters: The "Maths Multiplies Your Choices" campaign'. *V.I.E.R Bulletin*, 66:29-38.

[51] Dobson, I.R. (2013) A Critical Examination of Existing Solutions to the STEM Skills Shortage in Comparable [European] Countries. Country Report: Finland. Contributing consultant report to 'STEM: Country Comparisons' project. On behalf of ACOLA, for the Australian Office for the Chief Scientist: Canberra. Available online, http://www.acola.org.au/PDF/SAF02Consultants/Consultant%20Report%20-%20Finland.pdf

teachers improve their use of ICT in science and mathematics classes through a program known as *Intel Teach*[52].

Gender sensitive pedagogical approaches have also been successfully implemented. The Pollen project in Europe promoted the use of inquiry based science education, and gender inclusive practices in school science. Similarly in Korea, high school programs have used creative problem solving and research activities, in place of more traditional teaching approaches in order to attract and promote the study of the natural science and engineering among girls. This program is known as the Women's Academy for Technology Changer in the 21st Century (WATCH 21)[53]. This program also engaged college level students in new pedagogical approaches. Participants report that these approaches were both enjoyable and influenced their career choices[54].

Excursions beyond the school setting, as well as expert visitors to the school, have also been found to make STEM studies more attractive and interesting to girls. The Gender Issues, Science Education and Learning (GISEL) project in Finland reported in 2005 that female students preferred engaging in visits to industry and museums, as well as engaging with experts in their science classes, more than the normal science classes they had experienced.

Industry or employer led measures

While many features of the STEM workplace have long been considered problematic in attracting and retaining women, there are effective measures that can be implemented in industry or university environments. First, employers require motivation. Engineers Australia produced an *Industry Blueprint* to identify and describe potential programs and strategies to encourage and retain women to work in the engineering profession[55]. The Blueprint is based upon recent research, and acknowledges a number of important business outcomes that might act as an incentive for employers to act. For example, they cite creativity and productivity gains, greater retention of staff, more extensive scope for recruiting the best and brightest, and improved client relations. Importantly, the Blueprint identified around 30 strategies for which evidence of success can be reviewed. Key items include scholarship programs for female students, industry events at schools and university campuses,

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[52] Drori, G.S. and Netivi, A. (2013) *STEM in Israel: The Educational Foundation of 'Start-Up Nation'*. Contributing consultant report to 'STEM: Country Comparisons' project. On behalf of ACOLA, for the Australian Office for the Chief Scientist: Canberra. Available online, http://www.acola.org.au/PDF/SAF02Consultants/Consultant%20Report%20-%20Israel.pdf

[53] Jon, J. and Chung, H. (2013) *STEM Report: Republic of Korea*. Contributing consultant report to 'STEM: Country Comparisons' project. On behalf of ACOLA, for the Australian Office for the Chief Scientist: Canberra. Available online, http://www.acola.org.au/PDF/SAF02Consultants/Consultant%20Report%20-%20Korea.pdf

[54] *ibid*.

[55] Engineers Australia (2012) *Women in Engineering: Industry Blueprint of Successful in-house Professional Women's Programs*. Author: Canberra.

ensured gender pay equity, flexible work practices (including part-time, job share and leave of absence), mentoring programs, child care facilities, management awareness and training, and organizational mission to recruit equal numbers of male and female graduates.

Raising awareness of gender issues in mathematics and other STEM fields in the workplace is critically important. The awareness can enable employers to, for example, introduce more female perspectives into human resources decisions and policies, as well as provide greater transparency in funding procedures, promotions and nominations for top positions. In Korea, awareness is particularly important, and so the focus of key programs, such as Women in Engineering and Women in Science and Technology, which both provide information, policy research and direct career support to employed professionals. Awareness is particularly important for reducing bias. While many may espouse ideas of gender equity, there is often significant implicit bias which creates a problematic work environment, negative feelings between colleagues, poor hiring practices (though not deliberately so), and underrating of female employees in assessments for promotion and funding[56].

Improved work-life balance has been found to be a particularly productive approach to improving the gender balance in the STEM workforce[57]. In particular, having young children has been found to be detrimental to career advancement. Consequently, the flexibility of time commitments, particularly for parents, is an ideal place to start in instating measures for improvement. In Finland, Norway, Slovenia and Sweden the contracted period of employment for researchers is simply extended according to any time taken for childbirth or parental leave, with males encouraged to use this provision as well. In the United Kingdom, the Athena project established in 1999 attempted to improve women's career prospects in STEM fields in the university sector. Women were provided with personal and professional career support, departmental heads were made aware of the gendered issues and challenges, and regulatory modifications within the departmental cultures were made to support better work life balance.

Combining approaches – Government led consistency

To address the under representation of women in STEM disciplines in an effective and sustainable way, it is important that there by consistency of political will, and the engagement of an array of potential levers of influence. While many of the measures discussed above have had their local success, the most impactful changes must be diverse and gain broad support.

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

[57] UNESCO (2007) *Science, Technology and Gender: An International Report*. Science and Technology for Development Series. UNESCO, Division for Science Policy and Sustainable Development.

In Japan, where female participation in STEM fields is even lower than in Australia and the western world, a consistent effort has been in play for a few years[58]. The measures include a government commitment and system-wide targets that are specific enough to allow accountability. Industry and employer led measures have included the provision of child care facilities, direct employee support and career guidance, private investments in career counseling and school activities through corporate social responsibility programs, financial incentives at all levels through private sponsorships, and incentives for employers to improve work environments. Within schools, challenging and authentic learning activities, career counseling programs, and positive encounters with role models have also been instigated. Parents and teachers have been engaged in activities to encourage cultural shift in their views of girls' career decisions. Even industry bodies have engaged in programs to encourage young women to aspire to study and careers in STEM disciplines, through providing information and counseling services, as well as hosting events. The outcomes of these measures have been positive, with one prefecture reporting an increase of 50% in the numbers of school girls choosing STEM courses in higher education between 2002 and 2011[59].

In the United States, a presidential commitment and interest on the part of the first lady has helped spur along consistent national strategy to improve women's engagement in STEM[60]. The Administration's commitment comes in the form of a 5-year strategic plan and coordination of governmental efforts, and has included improvement to transparency through better data collection and dissemination, expanded career opportunities and financial incentives. Furthermore, partnerships are being fostered between governmental agencies to tackle the problem, with the National Aeronautics and Space Administration (NASA), Girls Scouts and the Department of Education just some of the bodies involved. Together, these bodies have engaged in providing inspirational and authentic learning experiences for school girls in the sciences, and financial incentives to individual schools to improve teaching, resources and professional development opportunities available. The Administration has reviewed legislation and legal protections to female students and employees to ensure equality opportunity under the law. These measures included the provision of financial incentives to schools and other institutions to ensure equal access to STEM-related resources and educational programs. The government has also attempted to play a role in reducing the challenges women face in the STEM workforce. They have championed career-life balance initiatives through the office of the First Lady, and provided financial incentives and grants to reduce existing

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[58] Ishikawa, M. and Moehle, A. (2013) *STEM Country Comparisons: Japan*. Contributing consultant report to 'STEM: Country Comparisons' project. On behalf of ACOLA, for the Australian Office for the Chief Scientist: Canberra. Available online, http://www.acola.org.au/PDF/SAF02Consultants/Consultant%20Report%20-%20Japan.pdf

[59] *ibid*.

[60] Executive Office of the President (2013) *Women and Girls in Science, Technology, Engineering and Math (STEM)*. Office of Science and Technology Policy: Washington D.C. Available online, http://www.whitehouse.gov/sites/default/files/microsites/ostp/stem_factsheet_2013_07232013.pdf

barriers. Furthermore, the National Institutes of Health (a key scientific funding body in the United States) has been instrumental in ensuring programs take into account time away from work to raise children and attend to other family responsibilities when awarding funds to researchers. Finally, the Administration acknowledges the importance of direct supports in the form of role models and mentoring programs. Presidential appointees include many talented women in positions related to STEM leadership, while an official speaking program ensures successful women have the opportunity to engage with young women and inspire their career goals. Governmental departments have programs to connect female engineers and scientists to undergraduate students, including at NASA.

These two examples are important, as they represent the most coordinated efforts to improve women's engagement in STEM. While internationally comparative statistics are yet to reveal the extent of improvement, the research is clear that such consistent efforts are indeed required to ensure the next generation of women choose to pursue STEM.