Keynote: The Age of STEM: Science, technology, engineering and mathematics policy and practice globally

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Abstract

Globally, science, technology, engineering and mathematics (STEM) education, research and development (R&D), and innovation are considered critically important for national productivity, economic competitiveness and societal wellbeing. This paper explores the findings of the STEM: Country Comparisons project that considered STEM in East Asia, the Anglo-sphere, Western Europe, Latin America and the Middle East. The research revealed a global turn to STEM, and this paper discusses trends and parallels regarding government STEM policy and structural responses, school and tertiary level STEM education participation, comparative performance through PISA and TIMSS assessments lenses, STEM R&D, and issues concerning gender and under-represented groups including Indigenous peoples. The paper discusses programs and solutions including curriculum and pedagogy reform, teaching-related initiatives, and strategies to redress current systemic disparities.

Context for global interest in STEM

In the age of the global knowledge economy, STEM (science, technology, engineering and mathematics) is considered critically important for national economic performance. STEM is also essential to address societal challenges concerning the environment, health and wellbeing, and food and water.[1] The STEM challenge is conceived globally in human capital terms; where STEM is instrumental in ensuring sufficient human resources for economic development and innovation. As Freeman, Marginson and Tytler state (2015), 'there is no contemporary nation with an economy both vigorous and well integrated that is not also strong in STEM'.[2] Participation and performance in STEM disciplines at the school and tertiary level, and STEM research and development (R&D) - essentially supply questions - have received much attention globally, frequently against a backdrop of "STEM crisis".

While the narrative links demand for STEM skills and economic competitiveness, STEM policy responses are principally focused where governments have regulatory or funding responsibility, namely school education (participation, performance, curriculum, pedagogy, teaching and assessment regimes) and R&D. There is less policy focus on tertiary level STEM participation, technical or vocational education and training (VET) or workforce development.

1 Office of the Chief Scientist, 2013a.
2 Freeman, Marginson and Tytler, 2015 (in print).

STEM: Country Comparisons project

The *STEM: Country Comparisons* project was initiated by Australia's Chief Scientist, Professor Ian Chubb, to contribute to the development of a coherent STEM policy response. The project was funded by the Australian Council of Learned Academies (ACOLA) as a Securing Australia's Future (SAF) project under an Australian Research Council (ARC) LASP grant. The terms of reference for the *STEM: Country Comparisons* project are as follows:

- Trends in STEM enrolments.
- Access of STEM graduates to the labour market.
- The perceived relevance of STEM to economic growth and well being.
- What other countries are doing to address declining STEM uptake and its impact on the workforce. Strategies, policies and programs used to enhance STEM at all levels of education, and judgement concerning the success of those programs.
- Are measures put into effect in other countries and cultures successful, and how has this been evaluated?
- Could, and should, such measures be applied in the Australian context, taking into account our cultural diversity?
- What are the implications of the application of culturally appropriate measures in Australia and will the policy framework need to be modified to accommodate them?

The project was chaired by Professor Simon Marginson, formerly of the Centre for the Study of Higher Education (CSHE) at the University of Melbourne, supported by Professor Russell Tytler, Deakin University as deputy chair. The project was overseen by an Expert Working Group (EWG) comprising fellows of Australia's learned academies, and managed by Brigid Freeman at the University of Melbourne.

STEM: Country Comparisons International comparisons of science, technology, engineering and mathematics (STEM) education was presented to the Prime Minister's Science Engineering and Innovation Council (PMSEIC) through the Office of the Chief Scientist (OCS). Recognising the interest globally in STEM policy borrowing, key researchers from around the world who had participated in the *STEM: Country Comparisons* project contributed chapters to *The Age of STEM: Educational policy and practice in science, technology, engineering and mathematics across the world* (eds. Freeman, Marginson and Tytler), which will be published in 2015 by Routledge.

Methodology

The *STEM: Country Comparisons* project commissioned 23 reports, principally including country and regional reports which investigated (guided by the terms of reference above) the following:

- Attitudes towards STEM, and the priority given to STEM, in: families, the community/media, government, educational institutions, employers and professional bodies.
- The perceived relevance of STEM to economic growth and well being.
- Current patterns of STEM provision in schooling, including STEM in primary education, and its influence on later participation in STEM; enrolments in STEM disciplines in secondary education; STEM provision, and participation, in tertiary (university and non university) education; and trends since 2005 in those secondary and tertiary enrolments.
- The role of STEM disciplines in both general education and vocational and occupationally-specific programs in education and training.
- Student uptake of STEM programs and factors affecting student performance and motivation.
- Access of STEM graduates to the labour markets, and labour market take-up of STEM knowledge and skills.
- Strategies, policies and programs used to enhance STEM at all levels of education, and judgment concerning the success of those programs.

The project also commissioned a small number of special interest reports focussed on Indigenous peoples and STEM, the Australian labour market, “identity”, and international agencies involved in international assessments and reporting. A report exploring Australian STEM policy, participation and performance was undertaken to provide baseline information regarding Australia's status.

Table 1: Country and regional reports, and special interest reports prepared for the STEM: Country Comparisons project

COUNTRY AND REGIONAL REPORTS					SPECIAL INTEREST REPORTS
ANGLO-SPHERE	**EUROPE**	**ASIA**	**LATIN AMERICA**	**MIDDLE EAST / AFRICA**	
United States	Western Europe Regional Report (Belgium, Denmark, Germany, the Netherlands, Norway, Sweden, Switzerland)	China	Argentina	Israel	United States Indigenous
Canada		Taiwan	Brazil	South Africa	Canadian Indigenous
New Zealand		Japan			Australian Labour Market
United Kingdom		Singapore			Literature Review: Identity
Australia		South Korea			International Agencies
	Finland				
	France				
	Portugal				
	Russia				

<u>Key comparator countries: characteristics, lessons and policies</u>

China

China’s economy is booming. It is now the second largest in terms of gross domestic product (GDP) after the United States. China’s long history of science education encompasses a concurrent focus on scientific literacy and elite science development.

There is a strong commitment to learning through self-cultivation, with effort rather than innate talent seen as the key to academic success. The education system is 'teacher-centred, theory focused, national examination oriented, and homework supplemented'.[3] Participation in school education mathematics is high as all students in year 12, regardless of whether they track into the science and engineering, or arts division, undertake compulsory mathematics. All students who track into the science and engineering division in year 12 undertake compulsory science (physics, biology and chemistry). Performance in school science and mathematics, as measured through the Programme for International Student Assessment (PISA) (Shanghai) and Trends in International Mathematics and Science Study (TIMSS) (Hong Kong Special Administrative Region) international assessments, is extremely high.[4] School science teachers are discipline specialists, participate in induction and ongoing professional development and have transparent career structures.

China's tertiary level education system has expanded very rapidly in recent years, including the number of higher education institutions (HEIs), research institutes (RIs) and students enrolled in tertiary level programs. The number of students enrolled in tertiary level STEM disciplines is very high at both the undergraduate and doctoral levels. At the undergraduate level, nearly one third of enrolments are in engineering, while at the doctoral level, 71 per cent of commencements were in science-related programs, the majority of which were in engineering. Gender disparities are evident in both tertiary level STEM disciplines, and the R&D workforce.

China's education system emphasizes national standards linked to standardised textbooks and teaching plans, and examinations. New Curriculum Reform, supported through the government's *National Mid and Long-term Education Reform and Development Framework 2010-2020,* has involved the incorporation of inquiry-based teaching and learning, hands-on practical exercises, and student centred learning[5] to develop scientific literacy. Science Experimental Classes (SEC) involve talented students attending science Olympiads and other elite education initiatives. There are also a variety of supplementary programs more broadly, including after-school activities and second classrooms.

The *Medium- and Long-term Plan for S&T Development 2006-2020* (MLP) provides a framework for China's significant investment in basic and applied R&D and innovation, implemented through the *12th Five-Year-Plan for S&T Development (2011-15)*. Poverty reduction continues to represent a key objective as China remains an emerging economy. China's central government is investing very heavily in research – second only to the United States in terms of gross domestic expenditure on R&D (GERD).[6] Investment in engineering and technology science R&D is prioritized. Investment in leading universities, research institutes and research laboratories includes initiatives such as Project 211 and Project 985; the latter which aims to increase the number of China's World-Class Universities (WCUs). Other initiatives include University science

[3] Gao, 2013a, p. 14.
[4] The China PISA results are for Shanghai (refer: http://www.oecd.org/pisa/aboutpisa/shanghai-china-pisa.htm). The China TIMSS results are for Hong Kong SAR (refer: http://timssandpirls.bc.edu/).
[5] Refer to the *National Mid and Long-term Education Reform and Development Framework (2010-2020).*
[6] OECD, 2013.

and technology parks, and technology projects fostering industry partnerships and innovations.[7]

Taiwan

Similarly Taiwan's economy is growing rapidly, with Taiwan referred to as one of the "Four Asian Tigers" with a mission to be the "Green Silicon Island". Taiwan's school education system emphasizes 'training scientific research capacity and skills; acquiring science-related knowledge and concepts and fostering of the scientific attitude'.[8] Students are tracked from year 10 into either vocational or academic education; however, science and mathematics only become optional in grade 12. The growing number of students entering technical/vocational schools (rather than traditional senior high schools) predominantly focus on technology subjects.

The number of students in school science and mathematics is decreasing due to demographic changes (that is, the decreasing birth rate). Mathematical literacy, as measured through PISA and TIMSS, is very high, while scientific literacy is also high. School curriculum is focused on both "science for all" and "science elite". The *National Education 9-Year Curriculum Outline* integrated science streams into one science subject - natural science and living technology. The *Senior Secondary School Curriculum Outline* strengthens science and mathematics knowledge of all students. Curriculum and pedagogy reforms are progressively moving towards student-centred learning that engenders active research and exploration, creativity and critical thinking skills, and imbues the scientific attitude. School teachers are well qualified, with nearly half of all senior secondary school teachers (47 per cent) holding Masters qualifications.[9] Participation in tertiary level STEM disciplines, particularly engineering, medicine and science, is very high at both undergraduate and postgraduate levels, although there have been recent declines. Again, there are gender disparities in terms of post-graduate enrolments in STEM disciplines, most particularly at the doctoral level; however, the gap is narrowing.

The Taiwanese government's commitment to science and technology is longstanding, with national science and technology plans dating back at least to the 1950s. School curriculum outlines emphasize problem-solving, independent thinking and scientific literacy, and are ability- rather than knowledge-oriented. The *Teacher Education Law* establishes pre-service training requirements. Teachers are increasingly being given autonomy and science teachers participate in professional development. The *Development Plan for World Class University and Research Centres for Excellence*, while not STEM-specific, seeks to increase the number of World Class Universities (WCUs) by injecting funding into twelve leading universities (the T12 universities), and encouraging international research collaborations. Investment in research prioritizes engineering and technology, and natural science. There is an emphasis on industry-education collaboration and commercialisation, particularly with respect to fundamental R&D. For example, the Ford Company partners with the technical university. Technology centres and incubators are also supported. The government is

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7 Gao, 2013a.
8 Gao, 2013b, p. 3.
9 Gao, 2013b.

increasingly focusing attention through science and technology policy, R&D programs, and a proposed dedicated Ministry.[10]

Japan

Japan's strength as a research, development and technology (R&D&T) power has been shaken in recent years following natural disasters including the Great East Japan Earthquake and consequent Fukushima nuclear plant accident. Declining public enthusiasm for science and technology has translated into declining school mathematics and science participation (particularly physics), and declining tertiary level participation in undergraduate STEM disciplines. At the doctoral level, the number of graduates from STEM disciplines has increased due to overall student number growth, while the proportion has not. Gender disparity, dubbed the "East Asian Syndrome", is notable in both tertiary level undergraduate and postgraduate STEM disciplines, and critically, in the R&D workforce.

Japan's formerly high science and mathematics performance, measured by PISA, declined in 2003 leading to "PISA shock" and a series of curriculum reforms aimed at redressing former curriculum content reduction. Japan's education system maintains a dual focus on scientific literacy ("science for all") and elite education ("science for excellence"). Teachers are highly regarded, participate in continuous professional development, and receive competitive remuneration; however, there are concerns about the apparent lack of science and mathematics teachers' discipline knowledge.

The Japanese government's *Science and Technology Basic Law* of 1995, while not a national STEM policy, establishes the framework to progress science and technology for societal and economic development. The law is administered through the Council for Science and Technology Policy led by the Japanese Prime Minister. The *4th Science and Technology Basic Plan* targets gender equity in STEM. At the school level, the Super Science High Schools program provides elite science and mathematics education in collaboration with universities and supports Olympiad participation. As noted, the plan reverses the former "relaxed education policy" and refocuses on scientific and mathematical literacy, and problem-solving. At the tertiary level, Japan remains a leading science and technology R&D power, having the third largest number of researchers after the United States and China, while concurrently having long had one of the highest ratios of researchers per thousand workers since the 1980s.[11]

Korea

The Korean government has long held a deep commitment to science and technology, attributed as contributors towards Korea's economic competitiveness and growth. Korea performs exceptionally well in terms of mathematics and science international assessments (PISA and TIMSS), despite the fact that they are not compulsory in senior secondary schooling. Participation in school-level mathematics and engineering, in decline since the 1990s, has recorded increases in recent years. Teachers, employed by the government, are well qualified and receive STEM-specific professional development. At the tertiary level, the number of students enrolled in engineering and

[10] Gao, 2013b.
[11] Ishikawa, Fujii and Moehle, 2013.

natural sciences undergraduate programs increased slightly from 2005; however, not as quickly as in other programs (notably social sciences). There are persistent gender disparities that begin in schooling and worsen as the education level increases. Despite Korea's obvious strength and interest in science and technology, there are serious concerns regarding flagging attitudes to science and mathematics, with employment in STEM fields no longer respected, or well rewarded in terms of remuneration.

The Korean government has had a long term commitment to planning for science and technology with five-yearly plans from the early 1960s.[12] In recent years Korea has reoriented STEM to STEAM (science, technology, engineering, *arts* and mathematics). This "STEAM" strategy aims, through the inclusion of arts, to better connect school education with university education and R&D, and drive curriculum reform by introducing creativity and critical thinking. STEAM aims to increase students' 'interest, self-efficacy, scientific attitudes, achievement, divergent thinking, and even enrolment'.[13]

In Korea science and technology policy is overseen by the National Science and Technology Council (NSTC), encompassing the Prime Minister and key STEM-related ministries. The second *Master Plan for Educating and Supporting Human Resources in Science and Technology (2011-2015)* seeks to foster a creativity-based economy. Korea's science and technology focused institutes include the Korea Institute for the Advancement of Science and Creativity (KOFAC) which promotes science, the World-Class University Project and specialized science and technology institutes including the graduate school Korea Advanced Institute of Science and Technology (KAIST).[14]

United States of America

In the United States, authority and funding for public school education is largely devolved. Concerns have been expressed about declining school student participation in science and mathematics, variability in achievement based on location (suburban, urban and rural), and under-representation in STEM based on gender, ethnicity, and socio-economic status (SES). The level of discipline specialisation has also been raised as an issue in terms of mathematics and science teaching. National Assessment of Educational Progress (NAEP) results reveal small achievement differences between males and females, and racial/ethnic groups. The United States ranks at or below OECD averages for PISA science and mathematics assessment results, while TIMSS results suggest some improvement in mathematics performance. While the *No Child Left Behind Act of 2001* introduced testing of school students' literacy and mathematics proficiency, disaggregated by gender and ethnicity, implementation at the state level varies such that cross-state comparative analysis is not possible. The majority of first year undergraduate students take at least one STEM credit, but enrolment in STEM majors is considered to be too low by the United States government. Overall, participation in bachelor-level STEM programs is growing, largely through increases in health and biological sciences. Participation in STEM disciplines at the post-graduate level is growing, noting that international students comprise almost one third of these

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[12] For example, refer to the *First Master Plan for Educating and Supporting Human Resources in Science and Technology (2006-2010)* and *Second Master Plan (2011-2015).*

[13] Kim, 2010, cited in Jon and Chung, 2013.

[14] Jon and Chung, 2013.

post-graduate STEM enrolments. In terms of the labor market, it is widely held that there are insufficient STEM graduates to meet the country's economic growth and competitiveness requirements; however, this is subject to considerable debate.

The concerted effort of the United States federal government, with respect to the STEM agenda, is reflected in a raft of key government reports.[15] The *America Creating Opportunities to Meaningfully Promote Excellence in Technology, Education, and Science Act of 2007* (*America COMPETES Act*) reauthorized in 2010, provides a comprehensive, legislative framework for STEM across the disparate state systems. The Act aims 'to invest in innovation through research and development, and to improve the competitiveness of the United States'.[16] Provisions span STEM education and teachers, R&D and innovation, and co-ordination of STEM agencies including the Office of Science and Technology Policy, National Aeronautics and Space Administration, National Oceanic and Atmospheric Administration, and National Science Foundation. The President's Council of Advisors on Science and Technology (PCAST) advises the President on science and technology.

The Cross-Agency Priority (CAP) goal aims to produce a further one million STEM graduates by 2020 through a multi-faced strategy:

(1) improve STEM teaching and attract more students to STEM courses;
(2) provide more opportunities for hands-on, real-world STEM activities through research experiences;
(3) address the mathematics preparation gap students face upon arrival to college;
(4) focus on women and underrepresented minorities; and
(5) identify and support innovation in higher education.[17]

As noted, based on numerous reports, key strategies are in place to consolidate the United State's global position in R&D, and incentivize STEM innovation. In terms of meeting anticipated labor market unmet demand at the para-professional level (that is STEM certificate and associate degree level), policy responses include facilitated immigration of STEM qualified workers, and extension of visas for PhD international students.[18]

Western Europe

At the senior secondary school level in Western Europe, participation in mathematics and science is highest for males in Norway, Sweden and France, and for females, in Norway, Sweden, France, Finland, Switzerland, Germany and Denmark. Performance in many Western European countries, as measured by PISA and TIMSS, is extremely high. Finland, Liechtenstein, Switzerland and the Netherlands scored highly on the PISA

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[15] For example, refer to *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future* (2005), the *National Action Plan for Addressing the Critical Needs for the US Science, Technology, Engineering and Mathematics Education System* (2007), *Prepare and Inspire* (2010), *Building a Science, Technology, Engineering and Math Education Agenda* (2011), *Competitiveness and Innovative Capacity in the United States* (2012), and *Engage to Excel* (2012).

[16] United States Government, 2007, p. 2.

[17] Maltese, Potvin, Lung and Hochbein, 2015 (in print).

[18] Maltese, Lung, Potvin and Hochbein, 2013.

2009 mathematical literacy assessments, while Finland, Estonia, the Netherlands and Germany scored high on the PISA 2009 scientific literacy assessments.[19]

At the tertiary level, participation in STEM disciplines is highest in Finland, Sweden, Germany, Switzerland and France. However, gender disparities persist in tertiary level STEM disciplines, most technical education enrolments and the STEM labour market despite the fact that women outnumber men in absolute terms at the tertiary level in many countries. In the wake of the global financial crisis, financial literacy has provided a focus for systemic attention. In Western Europe, STEM-related research findings are influential in shaping policy and programmatic responses most notably including the ROSE[20] and IRIS[21] comparative projects.

Western European countries have had a longstanding commitment to STEM. This commitment is articulated in national STEM or science strategies in Austria, Germany, France, Ireland, the Netherlands, Norway, Spain and the United Kingdom. These policies aim to improve the image and knowledge of science, increase participation, improve science learning, and address gender disparities and industry skill needs. These strategies reflect jurisdictional contexts, not least with respect to state structure (federation/'federation-like'/unitary). There is also a range of regional, European Union STEM initiatives such as European Schoolnet (a teaching and learning focused initiative connecting European education ministries),[22] the Scientix science education portal,[23] the Science Pedagogy Innovation Centre for Europe (SPICE)[24] and EU Science: It's a girl thing![25] initiative.[26]

United Kingdom

The United Kingdom has a high performing school education system, despite relative slippages in PISA and TIMSS rankings in recent years. Secondary school mathematics performance, at the General Certificate of Secondary Education (GSCE) level, has increased in recent years, as has participation in A Level mathematics. Participation in A Level science has fluctuated. Absolute increases in higher education participation have contributed to increased participation in tertiary level STEM disciplines.

The United Kingdom is strong is STEM research, with many leading centres of excellence and research laboratories. The United Kingdom's *Science & Innovation Investment Framework 2004-2014* focuses on World-Class Universities (WCUs), research and laboratories respondent to the economy, business, commercialisation and knowledge transfer. The policy also focuses on the school sector with initiatives including the introduction of the national curriculum, compulsory science, mathematics

19 Roberts, 2013.
20 Relevance of Science Education (ROSE) (roseproject.no) is an international research project exploring attitudinal factors regarding science and technology learning amongst 15 year olds. ROSE has found that interest in science is inversely related to the level of development of a country.
21 Interest and Recruitment in Science (IRIS) (http://iri.uni-lj.si/data/Projekti/IRIS/irisarhiv/about-iris/index.html) is an international research project exploring young people's perspectives, particularly young women, regarding STEM-related educational choices. IRIS has found that the immediate family is influential in educational choices.
22 http://www.eun.org
23 http://www.scientix.eu/web/guest/home
24 http://eacea.ec.europa.eu/llp/project_reports/documents/comenius/all/com_mp_502244_spice.pdf
25 http://science-girl-thing.eu/en
26 Dobson, 2013.

and information communication technology in years 10-11, science teacher supply and professional development, and GCSE science.

Attention has also been given to participation and performance in education and research, and addressing disparities for ethnic minorities and women at the tertiary level. STEM-related initiatives include the establishment of a network of over 1,300 specialist science, technology, engineering or mathematics and computing schools and enrichment activities such as museums, zoos, planetariums, and botanical gardens. Networks include the National Science Learning Network[27] and the Science, Technology, Engineering and Mathematics Network (STEMNET)[28] that aim to share STEM resources and promote students engagement with STEM.[29]

Russia

Russia has a high performing education system, with historically high levels of participation in school science, and school mathematics that is compulsory to the end of schooling. Russian school students perform well in TIMSS science and mathematics assessments, but less so in PISA assessments, suggesting strength in content knowledge rather than reasoning. School education is delivered with a focus on project- and inquiry-oriented learning, and teachers are well qualified. Tertiary participation levels have also historically been high, both generally and in STEM disciplines, however, there are persistent gender disparities with respect to tertiary level participation in STEM disciplines, and participation in the STEM R&D workforce.

There is a strong policy emphasis on university research, commercialisation, technology transfer, and innovation through university/business partnerships. A Presidential target has been established that aims to increase the number of World-Class Universities (WCUs) to no less than five in the top 100 by 2020, and strategies are in place aiming to strengthen funding for engineering, medical and science programs, and higher education research. STEM initiatives include the Presidential Program to retrain engineers, gifted children programs such as Olympics competitions and festivals, and residential, specialist schools for advanced mathematics and science studies.[30]

South Africa

The legacy of apartheid continues in South Africa, including the challenges of poverty, unemployment and social inequality. The South African government is focused on generating economic growth, improving participation in education, while providing basic health services and social protection. While school education has been de-racialized and performance in former White schools is high, there is a long “tail” of underperformance and disparities remain at all levels of education for African, Coloured and Indian peoples, along with gender disparities. While participation in vocational education and training has declined significantly, enrolments in STEM

27 https://www.sciencelearningcentres.org.uk
28 http://www.stemnet.org.uk
29 Tomei, Dawson and Dillon, 2013.
30 Smolentseva, 2013.

disciplines at the tertiary level have increased to approximately one quarter of all undergraduate enrolments, and approximately half of all doctoral enrolments.

The *National Development Plan of the National Planning Commission* seeks to redress former injustices. At the school level, the Focus Schools Project – Dinaledi Schools target retention and progression to tertiary studies among black students from disadvantaged communities, and the Students and Youth into Science, Technology, Engineering and Maths (SYSTEM) project provides second chance senior secondary examinations. Various initiatives target teaching quality, including training, qualifications and discipline knowledge. In the tertiary sector, the key bodies are the South African Agency for Science and Technology Advancement (SAASTA) and South African Association for Science and Technology Education Centres (SAASTEC). The *R&D Strategy* seeks to strengthen university science and technology research that has examples of strength such as the University of Cape Town.[31]

Brazil

Brazil, as a rapidly emerging economy, is focused on addressing current low levels of school education participation and attainment, disparities between geographical locations (for example, the Amazon population), poverty reduction and social inequality. School education policy issues include improving access to basic education, education infrastructure, pedagogy and teacher qualifications. Participation in tertiary level STEM disciplines is low but growing, and there is unmet demand for STEM qualified workers, principally including engineers. There are a number of targeted initiatives, including *Bolsa familia* ('Brazil without poor'), Quilombola education (for Quilombola communities), *National Curriculum Guidelines for Indigenous School Education*, and a racial quota establishing quarantined tertiary level places based on ethnicity. A number of scholarship programs have been established to increase access to tertiary level studies, such as Science Without Borders and *Bolsa Universidade*. The *Education Development Plan 2011-2020* focuses on teacher training, recruitment and career paths, while the *Restructuring and Expansion Plan for Federal Universities* (REUNI) aims to increase participation at the tertiary level.[32]

Shared attributes

Based on the *STEM: Country Comparisons* report, the Office of the Chief Scientist distilled key attributes shared by STEM-strong countries, emphasizing the importance of teachers, compulsory science and mathematics, curriculum and pedagogy reform, industry support, and national policy frameworks:

- Highly esteemed teachers who are well paid working in meritocratic career structures.
- Compulsory focus on disciplinary content (unlike Australia) [see below].
- Active reform of curriculum and pedagogy with more engaging, problem/inquiry-based learning, critical and creative thinking.

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31 Khan, 2013.
32 Horta, 2013.

- Prestige attached to careers in science.
- Strategic (bipartisan) national STEM policy frameworks which provide targets, objectives, metrics, approaches, coordination and collaboration across institutions and initiatives.
- Targets to motivate collaborative action – e.g. the USA's target of one million additional college graduates with STEM degrees in the next ten years to address labour market shortages.[33]

STEM in Australia

In Australia, STEM participation and performance are a cause for concern. Participation in year 12 mathematics declined over the period 1992-2010, and this decline was compounded by movement from intermediate and advanced mathematics programs (frequently pre-requisites for tertiary level STEM disciplines) to elementary mathematics programs.[34] During this period participation in year 12 science also declined including biology, physics and chemistry.[35] In terms of performance on PISA assessments, average mathematical literacy results declined between 2003 and 2009, and disparities were reported with respect to both mathematical and scientific literacy for Indigenous students, students from non-metropolitan schools, and students on the basis of socio-economic status (SES).[36] Comparatively, Australia was outperformed by many countries in recent TIMSS assessments.[37] Further, the National Assessment Program – Literacy and Numeracy (NAPLAN) revealed serious concerns including a long "tail" of underperformance with respect to literacy and numeracy.

At the tertiary level, despite absolute growth in domestic undergraduate enrolments during the period 2002-2010, there was variation with respect to STEM disciplines. Growth in domestic undergraduate enrolments was predominantly in health sciences while natural and physical sciences stagnated then grew; engineering grew from a low base; information technology decreased; and agriculture and environment enrolments remained relatively static.[38] During this period domestic higher degree by research enrolments remained relatively static, noting some variation: health sciences grew; natural and physical sciences fluctuated; agriculture, environmental and related sciences remained steady; engineering and related technologies declined then returned to 2002 levels; and information technology declined.[39]

Australian federal government policy agendas have focused historically on school education, and science and innovation. This is reflected in discrete policies addressing schools, teaching, language, literacy and numeracy, under-represented groups including Indigenous Australians, universities, R&D, commercialisation and knowledge-transfer. Government policies also address labour market needs and vocational education and training (VET). A few Australian states and territories have also developed STEM-specific policies, which reflect their narrower scope of responsibilities

33 Office of the Chief Scientist, 2013b.
34 Australian Mathematical Sciences Institute, 2012.
35 Office of the Chief Scientist, 2012.
36 Thomson et al., 2010.
37 Thomson et al., 2012.
38 Office of the Chief Scientist, 2012.
39 Dobson, 2012.

in Australia's federated structure.[40] There has been no coherent federal level framework for STEM policy; however, Australia's Chief Scientist has actively promoted this stating: 'The reality is that we can't relax. We can't be complacent. There can be no sense of entitlement. We must understand that we will get the future we earn'.[41]

Following the completion of our *STEM: Country Comparisons* project, the Office of the Chief Scientist recommended a package of reforms including the following:

> Analyse and evaluate cross-portfolio and cross government STEM education initiatives; ... Grow the pool of STEM informed people in the Australian community; Increase the quantity and improve the quality of the STEM cohort in higher education; ... Improve STEM education and awareness through development, streamlining and implementation of better teacher training and resources; ... Facilitate a national approach to STEM teaching and learning that meets the needs of Aboriginal and Torres Strait Islander students; ... Identify the skill base that employers require from STEM graduates in the workforce now and in the future; ... Develop a STEM Reference Panel reporting to the relevant Federal portfolio ministers, through the Chief Scientist, to report on STEM provision and participation in Australia.[42]

Subsequently, the Chief Scientist's *Science, Technology, Engineering and Mathematics: Australia's Future* (2014)[43] recommended a strategic government response to STEM focused on strengthening Australia's competitiveness, education and training for a STEM workforce ("science excellence") and scientific literacy ("science for all"), STEM research and international engagement. In response, the Australian government has just released the *Industry Innovation and Competitiveness Agenda*[44] aimed at increasing industry innovation, entrepreneurship and competitiveness through reduced regulation and industry taxation reform (such as encouraging employee share-ownership schemes). The policy establishes as one of six key initiatives: 'promote science, technology and mathematics skills in schools'.[45] Specific initiatives (at the cost of $12 million) include the following:

- assist to develop and implement 'Mathematics by inquiry' programmes for primary and secondary schools, which will be similar to other innovative online curriculum resources supporting the Australian Curriculum;
- assist to develop and implement the 'Coding across the curriculum' programme to enhance computer programming skills across the curriculum;
- provide seed funding to pilot an innovation-focused 'P-TECH' [Pathways in Technology Early College High School] styled secondary education initiative;[46] and

[40] Freeman, 2013a.
[41] Office of the Chief Scientist, 2013a.
[42] Office of the Chief Scientist, 2013b, pp. 2-6.
[43] Office of the Chief Scientist, 2014.
[44] Australian Government, 2014.
[45] Australian Government, 2014, p. vi.
[46] The P-Tech model was developed in the United States. It involves the delivery of an associate degree through partnership between school and tertiary level providers (that is, colleges in the United States), over a six year period. The Australian trials will involve students undertaking 'regular high school curriculum subjects alongside technical subjects such as computer programming, graphics, logic and problem solving. Workplace learning subjects including workplace visits, project-based learning and internships will be embedded in the curriculum and school timetabling' (Australian Government, 2014, p. 52).

- increase student participation in 'Summer schools for STEM students', particularly for girls, disadvantaged and Indigenous students, including those living in regional and remote areas.[47]

Australia's federal government will also establish the Commonwealth Science Council, comprising government, research and industry stakeholders to provide advice regarding national science and research priorities. In response, the Chief Scientist called on the Commonwealth Science Council to 'develop a strategic and whole-of-government approach to … STEM',[48] stating:

> I'm pleased to note that the Government will consider several specific proposals including those raised in our call for a strategy *Science, Technology, Engineering and Mathematics: Australia's Future* at the Science Council.

STEM policy around the world

There are notable variations with respect to policy responses around the world, which may be broadly differentiated as follows:

(1) high performing Anglo-sphere countries and a number of Western European countries;
(2) dynamic East and South East Asian countries with a Post-Confucian heritage; and
(3) emerging economies and education systems.[49]

High performing Anglo-sphere countries, including the United States, United Kingdom, Canada and New Zealand and a number of Western European countries frequently have national STEM policies aimed at addressing unmet labour market demand for STEM skills. Examples include the United States *America COMPETES Act,* United Kingdom's *Science & Innovation Investment Framework 2004-2014,* and Western European STEM or science policies in Germany, France, Ireland, the Netherlands, Norway and Spain. These policies are frequently located within a narrative of "STEM crisis" and declining relative performance according to PISA and TIMSS assessments. Western European national STEM or science policies span: public perceptions regarding science; public knowledge of science (scientific literacy); school-based mathematics and science (teaching and learning); interest and participation in school-based mathematics and science, tertiary STEM disciplines and the STEM workforce; disparities based on gender and for minority groups in education and employment-based STEM; and graduates with employer skills needs.

In contrast, dynamic East and South East Asian countries with a Post-Confucian heritage including Korea, Japan, China and Taiwan, and all with very high performing education systems and growing economies, have national science and technology policies emphasizing university- and industry-driven R&D and innovation. Examples include the Japanese *Science and Technology Basic Law* (S&T Law), South Korean *Second Master Plan for Educating and Supporting Human Resources in Science and Technology (2011-2015)*, and China's *Science and Technology Development Goal (2006-*

47 Australian Government, 2014, p. xiv.
48 Chief Scientist, 2014 (media release).
49 Freeman, Marginson and Tytler, 2015 (in print).

2020) and *National Mid and Long-term Education Reform and Development Framework* (2010-2020). These policies establish broad science and technology objectives regarding education reform and industry development.

Finally, emerging economies and education systems, including Brazil, Argentina, and arguably South Africa, have established national policies focused on quality education and emerging industry development. For example, Brazil's *Education Development Plan 2011-2020* emphasizes school education, teaching quality and teacher career pathways; and Argentina's *Bicentennial Strategic Plan* (2006-2010) prioritizes research and innovation, general scientific capacity, and development of targeted biotechnology and engineering industries. South Africa *National Development Pan of the National Planning Commissions* aims to redress injustices of the past, facilitate economic growth, and improve education, health and social protection.

There is a great deal of variability with respect to STEM policy objectives. Some policies seek to promote a positive *image* of science while others aim to increase *public engagement* with and *knowledge* of science, through increasing scientific literacy and understanding of the scientific method. Policy aimed at the school sector frequently focuses on strategies to enhance student engagement and ultimately, increase participation and performance in school-based mathematics and science, tertiary level STEM-disciplines and high-end STEM R&D. Policy may be aimed specifically at encouraging transition into the STEM labor-market. In many instances STEM policy seeks to redress disparities based on gender, ethnicity or race for minority groups including Indigenous peoples, and geographical location. STEM policy may establish mechanisms for co-ordination across STEM-related ministries, agencies and organizations (including scientific agencies, and R&D funding agencies). Policies may articulate annual and long-term objectives, common metrics or performance indicators to monitor progress, and establish an evaluation strategy. Policy actors include key participating STEM-related ministries, agencies and organizations.

STEM co-ordination agencies and organizations

STEM initiatives are co-ordinated and supported through a variety of structures, agencies and organizations reflecting these disparate objectives relating to STEM across the school and tertiary level education systems, R&D environments, and broader community. In some instances, STEM agencies connect current stakeholders or policy actors involved in the STEM agenda; in others they provide STEM-related advice to government, such as the United States Office of Science and Technology Policy.[50] Structures such as *inGenius*,[51] the European Schoolnet co-ordinating body for STEM education, have been established primarily to stimulate interest in science education. Similarly, the Korea Institute for the Advancement of Science and Creativity (KOFAC) promotes science and creativity.

Some organizations support science and mathematics education and teaching, such as Japan’s Training Centers for Core Science Teachers (CST), and Argentina’s National Institute of Teacher Training. Many organizations conduct science and mathematics enrichment activities. For example, Learning Experiences Outside The Classroom

[50] http://www.whitehouse.gov/administration/eop/ostp
[51] http://www.ingenious-science.eu/web/guest/home

(LEOTC), a New Zealand Ministry of Education curriculum project, provides authentic, hands-on, interactive learning for all ages; competitions such as Olympiads provide elite education; “real-world science” addresses the identity construct; and other activities provide remedial support, or “elite” education. Various networks provide opportunities to share good practices and STEM resources.

Some structures are focused specifically on education such as the Norwegian Centre for Science Education, the National Science Education Centre (LUMA) in Finland and *Academie des Sciences* in France. Others emphasize STEM research, such as the Institute for Engineering Sciences and Systems (INSIS) of the National Centre for Scientific Research (CNRS) in France, or more broadly technology focused, such as China’s National Technology Transfer Centres. In many instances, countries have research funding structures, such as the Canadian Natural Sciences and Engineering Research Council (NSERC) or Singapore’s A*STAR (Agency for Science, Technology and Research).

Some organizations collect and disseminate STEM statistics, such as the United States National Centre for Science and Engineering Statistics (NCSES).[52] Others specifically progress or explore Indigenous STEM science and education such as the Canadian Joint Task Force on First Nations and Metis Education and Employment, and Turtle Island’s Native Science Academy. Finally, others promote women’s participation in STEM, such as the Korea Advanced Institute of Supporting Women in Science, Engineering and Technology (WISET). As such there are a range of models for STEM-based structures respondent to divergent audiences, objectives and agendas.

Performance - scientific and mathematical literacy performance

Results from the Programme for International Student Assessment (PISA) exercises in 2009 confirm the dominance of the East Asian, South East Asian (Singapore) and some Western European countries in terms of mathematical and scientific literacy, with China (Shanghai, and Hong Kong SAR), Singapore, Korea, along with Finland, securing the highest ranked positions.

[52] http://www.nsf.gov/statistics/

Table 2: Mathematical and scientific literacy scores: PISA (2009)

MATHEMATICAL LITERACY SCORES		
1	Shanghai - China	600
2	Singapore	562
3	Hong Kong - China	555
4	Korea	546
5	Chinese Taipei	543
6	Finland	541
7	Liechtenstein	536
8	Switzerland	534
9	Japan	529
10	Canada	527
11	Netherlands	526
12	Macao - China	525
13	New Zealand	519
14	Belgium	515
15	Australia	514
16	Germany	513
	I	
19	Denmark	503
	I	
21	Norway	498
22	France	497
	I	
25	OECD Average	496
	I	
29	United Kingdom	492
	I	
32	United States	487

SCIENTIFIC LITERACY SCORES		
1	Shanghai - China	575
2	Finland	554
3	Hong Kong - China	549
4	Singapore	542
5	Japan	539
6	Korea	538
7	New Zealand	532
8	Canada	529
9	Estonia	528
10	Australia	527
11	Netherlands	522
12	Chinese Taipei	520
13	Germany	520
	I	
16	United Kingdom	514
	I	
23	United States	502
	I	
24	OECD Average	501
	I	
26	Norway	500
27	Denmark	499
28	France	498

Source: Roberts, 2013; data sourced from OECD, 2010.

In terms of mathematical literacy, the United Kingdom and United States rank below the OECD average (29th and 32nd overall), whereas in terms of scientific literacy, they rank above the OECD average (16th and 23rd respectively). Disaggregated by gender, there are no apparent differences for China, Finland, Korea, Japan, the Netherlands or New Zealand in terms of scientific literacy; however, males perform slightly better than females in terms of mathematical literacy on average.[53]

STEM breadth and depth

While the Australian system suggests an inherent tension between STEM breadth and STEM depth, high performing East Asian countries (amongst others such as Finland) demonstrate these characteristics need not be mutually exclusive. Freeman, Marginson and Tytler[54] report the consensus across countries that:

> (1) it is essential to foster scientific and mathematical literacy in all students to middle school level; (2) that it is desirable to persuade all students to maintain some STEM programs for as long as possible; and (3) to persuade more students in higher education to aspire to STEM learning and STEM-based careers, for example by shifting from professional programs in finance or law, to STEM studies and professions.

53 Roberts, 2013b.
54 Freeman, Marginson and Tytler, 2015 (in print).

Strategies to enhance STEM breadth and depth in school-level science and mathematics involve broadening engagement of all school students ("scientific literacy"), improving engagement and performance of under-represented cohorts ("STEM for equity") and increasing participation and achievement in intensive school science and mathematics and tertiary level STEM ("STEM for excellence"). [55]

Research regarding challenges facing Indigenous people's participation in Canada, New Zealand, United States and to some extent South Africa and Brazil highlighted the importance of culturally responsive curriculum and teaching, involvement of Indigenous elders, and respect for Indigenous knowledge. Specific strategies identified include courses facilitating transitions, outreach activities, industry placements, scholarships, culturally responsive higher education structures, activities and academic professional development.[56]

Curriculum, pedagogy and teaching

Globally, the challenges and apparent tensions facing school curriculum, pedagogy and teaching may be summarized as follows:

- Curriculum focus: Build knowledge of core disciplinary concepts, or build generic competencies such as problem solving, and creativity? ...
- Content or structure: Transform curriculum content, or restructure curriculum pathways?
- Pedagogy: Traditional teacher-centred or student-centred pedagogies?
- Autonomy or accountability: Will mathematics and science provision be more effectively enhanced through regimes of high accountability, or by supporting local autonomy?[57]

Curriculum and pedagogy reforms are being instituted to engage all students in the primary and lower secondary school years frequently with a view to encouraging increased participation in senior school science and mathematics, thereby increasing the "pipeline" for tertiary level study in the STEM disciplines. This pipeline is important for STEM R&D, which is conceived as the heart of the innovation system. Curriculum and pedagogy reforms have involved introducing problem-based, inquiry-based and student-centred learning, fostering problem-solving, inquiry, creativity, and critical thinking skills, alongside additional "out-of-school" enrichment activities. These skills supplement core disciplinary content, which underpins higher order learning. Several countries have also undertaken major reforms involving textbook content and teaching resources. Globally there is an emerging homogenization converging, on the one hand, discipline-focused, concerted teaching and learning, and on the other hand, innovative student-centred teaching fostering creativity and inquiry.

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[55] Freeman, Marginson and Tytler, 2015 (in print).
[56] Marginson, Tytler, Freeman and Roberts, 2013.
[57] Freeman, Marginson and Tytler, 2015 (in print).

In terms of education system structures, there are widely divergent models between the different STEM-strong countries examined, most notably with respect to academic and vocational tracking, compulsion, subject range/choice and pathways to technical and tertiary studies. The *STEM: Country Comparisons* project suggests discussion be held regarding 'firm bifurcation between a comprehensive STEM track, and a non-STEM track, in the final two years of secondary education [and the] development of STEM-heavy technical and vocational schools and tertiary institutes, alongside academic secondary schools and universities (the latter including some STEM)'.[58] Tensions are also evident with respect to teacher and school autonomy, and accountability and assessment regimes, notably in the United Kingdom where accountability and high-stakes testing regimes appear to constrain curriculum innovation and teacher professionalism.

Teachers are central to any discussion of school education quality and reform. Several countries demonstrably recognize the centrality of teachers and establish high qualification requirements (including discipline specialization in science and mathematics), commensurate remuneration and meritocratic career structures. In countries such as Finland teachers are held in high esteem and given significant autonomy. Many systems implement discipline-specific continuous professional development, provide teaching resources, and engender community respect. In others, such as Australia, debate turns to "quality" (conceived in terms of "teacher quality"), the introduction of credentialling standards and entry requirements. Many countries have introduced strategies aimed at increasing the number of school teachers with disciplinary specialisation, through initial teacher training and discipline-specific professional development.

STEM research

STEM doctoral research is key to the STEM R&D workforce, and innovation sector more broadly. A large proportion of doctoral graduates are in the science and engineering fields, led by France, China, Canada, Israel and New Zealand. In many countries, the number of doctoral graduates from STEM disciplines is growing faster than others. Most countries have more science doctoral graduates than engineering, however China, Japan and Korea have noticeably more engineering doctoral graduates. In all instances, women represent less than 50 per cent of science and engineering doctoral degree graduates, with participation lowest in Japan (15 per cent) and Korea (18 per cent). [59] Many countries have policies and programs in place to attract doctoral students generally, and to STEM fields specifically, increase the R&D workforce, and promote industry-education R&D-based partnerships. Immigration policies are also in place to recruit doctoral trained graduates, particularly in STEM disciplines.

Women and STEM

As noted through this paper, while there are variations between countries, globally women are under-represented in post-compulsory school science and mathematics, technical and vocational education and training, and tertiary-level STEM disciplines, including computing, engineering, manufacturing and construction, and sciences.

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58 Marginson, Tytler, Freeman and Roberts, 2013, p. 19.
59 OECD, 2011.

Women also remain under-represented in the STEM labour market, the R&D system and frequently the academic labour market. These disparities have been attributed to 'a range of causes including perceptions regarding STEM school, higher education and employment pathways, limited "conscience of a gender problem", employment conditions (such as parental leave and childcare provisions) and stereotypes'.[60] Key strategies aimed to redress these disparities include the establishment of targets and monitoring, tertiary education and R&D scholarships and fellowships, strategic funding for women researchers, mentoring programs, curriculum and pedagogy reform, and career counselling.[61]

Attitudes to STEM

Attitudes to STEM present a paradox: the public reportedly values the promise of science, while simultaneously holding reservations about science. For example, while the vast majority of United States and Chinese respondents (90 per cent and 86 per cent respectively) agreed that 'science and technology are making our lives healthier, easier and more comfortable', over half of United States respondents (55 per cent) also agreed that 'we depend too much on science and not enough on faith' and the majority of Chinese respondents (73 per cent) agreed that 'science makes our way of life change too fast' (Table 3). In many instances this disconnect is manifest in low engagement with, and participation in, school science and mathematics, tertiary level STEM disciplines and research, and the STEM labour market.

Table 3: Percentage of respondents who agreed with statements about science, by country

Statement	United States (2004 or 2010)[a]	Japan (2001)	South Korea (2008)	China (2001 or 2007)[b,c]	India (2004)	Malaysia (2008)[d]	European Union (2010)
Promise of science							
Science and technology are making our lives healthier, easier and more comfortable	90	73	93	86	77	84	66
With the application of science and new technology, work will become more interesting	76	54	85	70	61	71	61
Because of sceince and technology, there will be more opportunities for the next generation	91	66	84	82	54	NA	75
Reservations about science							
We depend too much on science and not enough on faith	55	NA	54	16	NA	39	38
It is not important for me to know about science in my daily life	14	25	30	17	NA	NA	33
Science makes our way of life change too fast	51	62	73	73	75	66	58

Source: Maltese, Lung, Potvin and Hochbein, 2013.

The pivotal role of the family with respect to STEM emerged as a key theme through the research: 'In many, if not all, countries parents are seen as key – often it is they that will decide whether socially positive attributes to STEM lead to STEM study and work'.[62] This is particularly the case in Post-Confucian systems.[63]

60 Freeman, Marginson and Tytler, 2015 (in print).
61 Marginson, Tytler, Freeman and Roberts, 2013.
62 Freeman, Marginson and Tytler, 2013, p. 4.
63 Marginson (2014) defines the features of the "Post-Confucian system" as follows: 'the comprehensive Sinic state, Confucian education in the home, an effective response to Western modernization, and economic growth sufficient to pay for educational infrastructure and research' (p. 91).

The TIMSS international surveys of 4th and 8th grade students illustrate attitudinal change over time, with younger students more receptive to science and mathematics. For example, 53 per cent of 4th grade students reported they "like science" (international average), compared with 35 per cent of 8th grade students. The notable decline with respect to science was repeated in terms of attitudes towards mathematics (48 per cent of 4th grade students declining to 26 per cent of 8th grade students). Similarly, the Relevance of Science Education (ROSE)[64] study identified a connection between the level of a country's development and attitudes to science and technology. Young people from developing countries such as Uganda, Ghana, Lesotho and Swaziland are more likely to agree strongly that science and technology are important for society than developed countries (with Scotland and Northern Ireland results the lowest).

Many East Asian and Western European countries, in addition to the United States and Canada have responded by reforming school science and mathematics curriculum to emphasize scientific literacy by focusing on "inquiry" competencies such as problem solving, creativity and critical thinking. Concurrently, student-centred and inquiry-based pedagogy reforms have been introduced to enhance science and mathematics engagement, learning and achievement.; however, reforms aimed at increasing student engagement introduce tensions between disciplinary content and generic, "inquiry" competencies and raise questions regarding the balancing act between "depth" and "breadth". They also introduce tension regarding accountability regimes required within the system, alongside growing levels of autonomy to enable school teachers' flexibility to innovate.

Programs

The *STEM: Country Comparisons* project revealed a wealth of STEM programs and initiatives including:

- Structures, consortiums and centres.
- School education (primary school level science and mathematics, funding, curriculum, pedagogy, participation, teaching quality, compulsory mathematics and science, science and mathematics university pre-requisites, high achievers and scientific literacy).
- Student engagement (attitudes to STEM education and the STEM workforce, identity).
- Tertiary education (vocational education, university education, R&D).
- Industry (including R&D and labour markets) and labour market.
- Transitions between institutions, to employment.
- Partnerships and enrichment activities.
- Girls and women, Indigenous peoples and other minorities.
- Public perceptions.

[64] http://roseproject.no/

- Inequality, poverty reduction and access to basic education.
- Monitoring, targets, evaluation and accountability.
- Financial literacy.

While different contexts and histories necessitate considered approaches to policy borrowing, there is much to learn from the wealth of examples identified through the project.

Conclusion

The global turn to STEM, while frequently based on narratives of "STEM crisis", is generating fundamental reforms spanning the school, technical and tertiary education sectors, and the R&D and innovation spaces. The *STEM: Country Comparisons* project identified a series of "keys to STEM success", starting with a coherent STEM or science and technology legislative or policy framework, supported by structures and organisations required for concerted and coordinated implementation. STEM-strong countries concurrently build both breadth ("scientific literacy") and depth ("STEM for excellence"), while redressing systemic inequities ("STEM for equity").

In terms of school education, curriculum and pedagogy reforms focus on building core disciplinary strength while simultaneously ensuring student engagement by delivering inquiry-based, student-centred learning. Such reforms reportedly foster the problem solving, creativity and critical thinking skills considered essential for innovation in the global knowledge economy. Ensuring disciplinary strength of science and mathematics school teachers, and providing discipline-specific, continuous professional development are key to teaching quality. The emerging homogenization, converging core disciplinary strength together with creativity and inquiry warrants further consideration to identify successful examples that have the capacity for transnational application.

Much more recognition and attention needs to be given to positioning the technical education sector as a key contributor to the STEM agenda. In terms of the tertiary level education sector, key success factors include increasing participation in both undergraduate and doctoral STEM programs, supporting the transition to the STEM R&D workforce including partnership arrangements with industry, and growing innovation capacities in the research sector including World-Class Universities (WCUs).

Unlocking the potential of under-represented groups, principally including girls and women, Indigenous peoples and those who are geographically isolated, will be key to addressing both scientific literacy agendas, and apparent unmet demand. Finally, attitudinal change, for young people, families and the broader community, will be imperative for ensuring that communities embrace the opportunities and realities of STEM, science and technology.

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