Development of the Science and Technology Workforce

A world in transformation

The world today is experiencing structural global transformations, many of which can be attributed to the fast pace of scientific discovery, development and innovation that has occurred in recent decades. Science, technology, engineering, and mathematics (STEM) are viewed not only as necessary to address complex societal challenges but also as critical underpinnings of economic advancement. For many nations, the need to develop a strong STEM workforce is a major priority to ensure growth and vitality of their economies. The UNESCO Science Report 2020 (UNESCO, 2021) highlights the varied levels of science development across the world, recognizing the differences between developed and developing countries in the science enterprise. Countries also vary in their capabilities to apply technological development and innovation to improve the living conditions of their societies.

Many countries have recognized that the key to economic growth and prosperity is the development of the social sciences and humanities in addition to the physical and natural sciences. The complementarity of the physical, natural, and social sciences with humanities has been studied for some time (Steward-Gambino and Rossmann 2015). It is argued that in the United States that the role of STEM has been key to innovation and global competitiveness and that higher education is considered vital for preparing future leaders. But, despite this importance, a prevailing view is that education must be extended to prepare a broadly informed citizenry in order for the country to meet the technical challenges of modernity and to maintain its democratic leadership in the world.

Scientific and societal change has also impacted how science is conducted. The sheer scope of societal problems that transcend national borders and the scale of resources required to address them have pushed the boundaries of scientific disciplines and underscored the importance of cross- disciplinary approaches. Interdisciplinary science has catalyzed new research areas and achieved previously unreachable solutions.

New challenges have also underscored the need for broader approaches encompassing international partnerships to take on global challenges such as those identified in the United Nations Sustainable Development Goals, and currently illustrated globally by the ongoing COVID pandemic.

Societal and technologies changes have also impacted how scientific research can be conducted. For example, the decreasing cost of technologies and options for increased mobility have lifted constraints on where researchers can work, considerably broadening the physical boundaries of the STEM research ecosystem. Increased mobility of STEM human capital may benefit scientific research overall but pose challenges for nations that suffer “brain drain” because fundamental research infrastructure including robust educational systems take time to build. A well-distributed circulation of the STEM workforce should be developed in all regions of the world.

The STEM research enterprise requires a workforce with differing levels of STEM education and skills that include technical training and high-level skill formation. Businesses play a role through their implementation of training policies that will improve STEM capabilities within their industries. The globalized nature of many industries, advances in computing and technology, and the changing conceptions of work and workplaces will continue to produce new occupations and jobs that in turn spur the constant refreshing of skills. In addition, the scope and scale of research ecosystems vary across nations, reflecting different levels of scientific establishment and different national interests and needs.

To build and expand a strong STEM workforce, nations must weigh needs for investment priorities across different sectors and interests. These considerations can be viewed as both needs and challenges for nations and governments, thereby presenting a varying spectrum of investment priorities across different nations. However, some needs are foundational. Nations would benefit from considering the following factors as they pursue STEM workforces for the future. An international view of needs and responses can be strategically built by considering the present global transformations.

Research funding councils have a key role to play in developing the STEM workforce at both national and global levels. Funding councils are instrumental in supporting the education and training of scientists and engineers, in focusing the direction of research in and across disciplines, and in promoting international collaboration to tackle problems such as climate change where individual countries cannot find solutions alone.

They also play a critical role in advising governments on the importance of investing in all levels of the STEM workforce to catalyze positive impacts on national and global economies. Funding agencies and councils can develop programs and policies that support effective paths to vibrant STEM workforces across scientific disciplines and career types that are inclusive of diverse communities.

One of the major challenges for funding agencies and policymakers is to closely interact in order to facilitate collaboration among public, private, and educational sectors toward the common goal of a STEM capable workforce. Synergy among these stakeholders could amplify coordinated efforts to achieve greater progress toward a vibrant, multifaceted research ecosystem.

The challenge for the Global Research Council (GRC) is to navigate an inclusive path where nations of varying sizes and levels of research establishment can chart their own course in the complex ecosystem of STEM human capital development. The GRC can provide insight to their respective communities that STEM, humanities, and the arts contribute to the strength of a nation by complementing each other. Key questions for research councils are how to finance both sciences and humanities and how to prioritize with limited resources. Research councils also have the opportunity to better define the policies that underpin integration of research from STEM and the humanities

Science and technology workforce development

STEM education, training, and career paths

Critical to all sectors of a strong STEM workforce are robust education and training that include clear paths to diverse careers within the STEM research enterprise. STEM education and training are prerequisites to the strong tertiary education and postgraduate training that research careers require.

Education and training of the STEM workforce are broad and complex with multiple roles and contributions from education, government, academia, and the private sector. Funding agencies and research councils can play a pivotal role in offering guidance to policymakers, as well as providing programs that can have catalytic and multiplicative effects, particularly on the academic career paths on which most councils focus. Funding agencies and councils are focused primarily on the STEM workforce at tertiary and postgraduate levels and the continuing career paths through the academic and other employment sectors. This is where GRC partners can have profound impact on STEM workforce development.

At the earliest educational levels, perceptions of STEM and STEM careers could be enhanced by incorporating the participation of teachers and parents. Providing greater access to professional learning in specific STEM disciplines, cross-curricular pedagogies, real-world problem-based learning, information on future careers and industry requirements, and identifying and disseminating best practice in teaching and learning will ensure that teachers have the capacity and confidence to facilitate deep learning of STEM. Further, teachers should be provided the means and training to demonstrate the importance of STEM to everyday life and future careers, which would engage and assist parents to encourage their children to pursue STEM.

The focus on early levels would also ensure that diversity, equity, and inclusion are incorporated early in STEM education and training and help to illustrate that STEM careers are open and accessible to all. The 2013 GRC Statement of Approaches on Building Research and Education Capacity laid out challenges for nations of differing economies and research infrastructures in building STEM capacity and offered principles and actions for GRC partners to address such challenges. These included equal partnerships among global collaborators, sharing good practices in research management to promote institutional capacity building, and sustaining a pipeline of diverse researchers and educators by funding across the research pipeline.

For inclusive STEM workforce development, funding agencies can provide funding opportunities to early-career researchers and communities traditionally underrepresented in STEM, as well as working to reconfigure the academic career paths to remove obstacles that prevent full participation of all communities. Sustainable funding instruments such as fellowship and professional development programs at all stages of careers can serve to recruit and retain researchers of all levels.

Diversity, equity, and inclusion

An equally foundational issue is that of diversity, equity, and inclusion. Diversity may refer to different communities, including gender, race, ethnicity, and economic status. Diversity can also reflect differing national interests in areas of STEM, diversity of skill levels, and diversity of career paths to pave a path to a STEM workforce with strength at multiple levels. It is important to recognize that national interests and needs in the STEM workforce are as diverse as their territorial needs. Investment in diverse skill levels and career paths can help to mitigate the risks of uneven workforce development focused on a very specific career sector or field, which may be vulnerable to rapidly evolving technologies and global markets. Industry or private sector involvement is critical. While there is still work to be done to help industries and professional associations to better identify and outline their workforce requirements for high and mid-level

STEM skills training, industries are often able to identify their immediate needs, and some capacity building schemes can be rapidly implemented to supply such a STEM-capable workforce. The implementation of public policies can positively impact their ability to develop and implement longer term perspective of skills that will be or might be required in specific industries. For example, the time frame required to build a capable workforce that includes the high-level STEM skills required for scientific research or engineering and the technicians and technologists necessary to support them is approximately a decade. [1]

Beyond the STEM workforce, STEM skills are also crucial for a workforce capable of solving problems, thinking critically, innovating, and implementing and developing new technologies. These skills are especially important considering the rapid change in technological fields and the automation of multiple non-technological industries. The impact of such changes inevitably alters the human resources demand, and countries need to be prepared to have a workforce with some level of STEM skills even if they do not work in STEM related areas.

A focus on diversity enables national economies to benefit from the contributions of a larger share of society; therefore, investing in inclusive workforce development across diverse communities, including race, ethnicity, gender, and economic status can lead to better economic outcomes overall and reduce inequities. Currently, the underrepresentation of women, indigenous peoples, and members of low socio-economic groups is evident not only in the STEM workforce but is also visible very early in their involvement in the study of STEM subjects in primary education.

<u>Gender</u>

As noted by many researchers, the advancement of women in science and engineering has been slow. Science and engineering are highly segregated by gender with both horizontal segregation between disciplines and vertical segregation between levels. Women choose careers in scientific fields at a lower rate than men, and the number of women in senior positions is substantially lower than the number of female doctoral students and in junior positions. Two explanations for this dynamic are the leaky pipeline and the glass ceiling.

The leaky pipeline refers to the tendency of female scientists to leave the academic sector in the course of their careers. The 'glass ceiling' reduces the proportion of women at the higher levels of the career hierarchy. Organizational and cultural barriers in the academic system may prevent women from career advancement. Female scientists more often pursue a collective model than male scientists do. However, evaluation procedures focus on individual rather than collective achievements. Female scientists also tend to have more collaborators than male scientists. Women motivate their collaboration primarily with mentoring strategies, whereas men tend to use instrumental and experience strategies. Studies also show the added value of the increase of women in science and engineering to the way researchers engage in interdisciplinary cross-fertilization, team-collaboration, field-creation, and problem-orientation.

In addition to gender, ethnic diversity has introduced different views into the Eurocentric knowledge perspective, inducing self-criticism and the awareness of the necessity of enlarging the scientific field to other cultures. The previously referenced study discusses the female domination of computer science in Malaysia. It offers a critique of a western bias in gender and technology studies and advocates for more context sensitivity and focus on the cultural embedding of gender and technology relations. The impact of digitalization and virtualization of science practices on gender dynamics in science practices is not well understood.

Challenges for GRC

A strong STEM ecosystem encourages schools, employers, and non-profits to work together to ensure that students graduate with both the technical and personal professional skills they need. The GRC can advise policymakers on the need to incentivize companies to invest in innovation and create promising new job opportunities for these graduates.

Funding councils can also help policymakers recognize the importance of focusing on research and innovation from different perspectives that attract investment or incentivize local industries to do more research. Through these efforts, graduates from STEM areas can find new job opportunities, preventing "brain drain" and sustainably accelerating each country into a knowledge-based economy.
In this regard, it is important for each country to be clear on the sectors that give them competitive advantages and to focus their efforts on these sectors.

Having a global approach to developing the STEM workforce is crucial to overcome the challenges inherent in building one. Sharing best practices and successful cases in different regions and varying scenarios can help funding agencies attain a better understanding of the steps and actions needed to bridge the gaps between demand and availability in the STEM workforce.

This could also help to mitigate a global STEM paradox: while education in STEM subjects has been recognized as a critical global need, many countries around the world are also facing increasing employment gaps in these fields. Key issues to resolve this paradox may be that the market is not designed to send effective signals to the various actors (students, workers, employers, and governments), to allocate the required funds for skill development.

Working in concert with global partners, funding councils can advise on developing flexible policies capable of evolving and adapting to the changing requirements of the STEM ecosystem that accommodate national interests while embracing technological advancements.

Successful strategies for GRC partners

Funding agencies and councils can adopt a number of approaches to bring together the interests of government, industry, and education to achieve a skilled STEM workforce, emphasizing the need for continued training and reskilling to maintain a vibrant workforce.

One approach is to conduct STEM workforce analysis and forecast future STEM skills requirements and sharing the findings across all sectors. STEM-related industries with high growth potential can be identified to under the impact of technologies on future work and the resulting skills requirements. There is a need to improve data sharing across industries, sectors, and portfolios to support decision-making.

Another approach is to encourage effective industry engagement with educational and research institutions to enhance professional learning, develop real-world problem-solving experiences, and promote awareness of STEM careers. Initiatives such as internships, work integrated learning, field work, and industry mentoring programs enable students to understand the portability of their skills and the array of career opportunities available.

Case Studies: Successful strategies and programs

The GRC could gather and publicize strategies, case studies, and examples of programs that have been successful in achieving strong and sustainable STEM workforces. Such programs may serve as models or templates for partner councils to adopt and adapt as necessary for their specific needs.

The world needs sustained collaboration to develop robust national and international STEM workforces to tackle the increasing challenges faced by all nations. The GRC can make a unique contribution to finding global solutions by disseminating partner councils' experience-based knowledge of successful programs and strategies.

Panama: Gender case study

A case study performed in Panama (SENACYT-PNUD, 2018) corroborated the "scissors effect" of gender distribution on research activities along an ongoing timeline. The effect indicates that more women than men are enrolled in higher education. However, further along educational and career paths, they account for barely half of the researchers, scientists, and technicians in the country in comparison to their male counterparts.

Some of the main findings of this study show that there is a gender gap as well as ethnic gaps in the exercise of basic rights of women, such as the right to sexual health, reproductive life, a life without violence, and political participation. The indicators analyzed show that, despite women having good health indicators, it is specifically in the sexual and reproductive health where they find main deficits of the right to health. The high maternal mortality and early motherhood in Panama place the country in a low position in the human development index considering the gender inequality.

Women encounter greater obstacles than men throughout their scientific careers and participate little in decision-making positions of the knowledge society in Panama. In the dimension of "knowledge economy" women have been the majority (59%) holding professional and technical positions, with a clear tendency of increase in the last twelve years. On the other hand, women hold 40% of the positions in top and middle management. Although improvement has been observed in the last decade, there are still important differences by field and level. In some of the scientific fields, especially in areas such as physical sciences, mathematic and statistics, as well as computer science and engineering, and the fields of industry, production, architecture, and construction, the traditional gender division is maintained. It is notable that even though women graduate from the University more than men representing around 65% of the total, men still represent the majority of graduates in the traditionally male fields. Most of the country´s researchers are men (more than 60%).

Additionally, there is a hierarchic tendency: the advantage of men is superior in the positions of researcher than in the positions of support personnel or personnel of scientific service and technician. A metaphor frequently used to explain the fact that women are underrepresented in STEM careers is the "leaky pipeline." Although girls perform as well as or better than boys in math and science at the primary and secondary levels, they are underrepresented in some STEM subjects, particularly engineering and computer science, at the tertiary level.

Multiple overlapping dimensions that interact in complex ways also have an influence on women´s education, employment, and progression in STEM careers.

Questions for discussion

There are many dimensions for research councils and funding agencies to consider, including:

- developing skills in critical fields;
- STEM workforce strategy and challenges;
- integrating skills development for sustained growth;
- effective STEM workforce education;
- adaptation to changes of the science and technology workforce in a global context;
- public policies to improves the development of the science and technology workforce; and
- synergy within key actors (academia, government, public sector, and NGO's).

Questions that GRC members have considered include:
What is the role of research councils in the development of a STEM workforce and how can these councils interact with universities and other knowledge institutions?

How would you define/frame the challenges to achieving a broad STEM workforce in your country? What are the barriers?

How are funding agencies promoting diversity and inclusion in the STEM workforce regarding gender, economic status, and ethnicity?

How can research funding agencies build national capacity while balancing the need to build global collaboration?

What are policy and strategic approaches to creating more public-private partnerships to develop a vibrant STEM workforce?
How do funding agencies demonstrate the benefits and impact of investment in STEM workforce

education nationally, as well as globally?

Overarching Considerations
Nations' interests in addressing national needs and challenges must be recognized while pursuing the global interest in building a STEM workforce. The global interest can be defined as the pursuance of a sustainable world as called for in the Sustainable Development Objectives.

Principles on the development of the science and technology workforce

1. A broad, vibrant, diverse, and inclusive STEM workforce across skill levels is critical to national and global research ecosystems, as well as national and global economies. Research funding councils should prioritize broad participation of researchers and STEM professionals, including early career researchers, women, and members of other groups underrepresented in STEM. Research funding councils should also embed diversity and inclusivity (including a strong focus on gender and intersectionality) into the development of the STEM workforce through collaborative efforts aimed at enhancing the preparation, increasing the participation, and ensuring the contributions of individuals from groups that have been historically underrepresented and underserved in the STEM enterprise.
2. Research funding councils should adapt to a changing research and innovation landscape by catalyzing innovation and advising key stakeholders across sectors to develop a multi-level STEM workforce that has technical and transferable professional skills.
3. Basic and applied STEM education research and training are essential to responding to rapid technological changes. Research funding councils should promote novel, creative, and transformative approaches to generating and using new knowledge about STEM teaching and learning to improve STEM education.
4. Mobility in careers both domestically and internationally contributes to development of skills in research and innovation and better cooperation among research organisations, private industry, non-governmental organizations, informal science centers, and other organisations. Research funding councils should support a variety of STEM career pathways and the development of transferable technical and professional skills to enable career moves, such as through reskilling and upskilling, and promotion of stronger relationships among common research foci and disciplines across sectors.
5. Building effective research teams and leveraging skills and knowledge are key to performing transformative research. Research funding councils should pursue mechanisms to fund interdisciplinary research and support international teams to catalyze scientific discovery and innovation.

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