The New York Academy of Sciences

THE GLOBAL STEM PARADOX

Workforce needs of the 21st century have raised a call worldwide for greater education in science, technology, engineering, and math (STEM). Yet, as more STEM students graduate, millions of STEM jobs in both developed and emerging countries are going unfilled. Why the paradox, and what is the solution?

REIMAGINING SOCIAL CHANGE

FOREWORD

For nearly 200 years, the New York Academy of Sciences has been bringing together thousands of extraordinary people worldwide, all working at the frontiers of discovery. In short, we regularly work with the brightest and best STEM (science, technology, engineering, and math) professionals. So why do we focus on STEM education – or rather the challenges inherent in STEM education today? And why are we focused on those individuals who are not getting the skills and support they need to become the STEM leaders of tomorrow?

IF THE PIPELINE OF FUTURE INNOVATION FAILS,
THE ACADEMY CANNOT FILL ITS MISSION TO:

- advance scientific research and knowledge,
- positively impact the major global challenges of society with science-based solutions, and
- increase the number of scientifically informed individuals in society at large.

Today what we see is a STEM education pipeline with holes, gaps, and weak points, from which students drop out—often at predictable points—due to lack of interest, engagement, help, or financial support.

This is why the Academy has worked for the past four years in New York and New Jersey to build an education program that pairs the expertise of the STEM community with hundreds of children in underserved communities; and we've done it with much success, garnering grants from the National Science Foundation and engaging in meaningful relationships with partner organizations who share our passion.

Proud as we were of these local successes, we know that STEM education challenges are global—and so must be the solutions. So, we are taking the model we have worked so hard to refine locally, and developing innovative mechanisms to scale our success globally by catalyzing novel public-private partnerships across sectors and borders.

The distillation of the STEM challenges and best practices contained herein will serve as lessons and focusing points for the Academy and our partner network of major corporations, government leaders, universities, and dedicated individuals that comprise the Global STEM Alliance. We hope this paper inspires others so that through a truly global effort, we can turn the STEM dilemma into tangible opportunities with positive outcomes on workforce development, local economies, businesses, and of course, the lives of students—our future STEM leaders and innovators, who will tackle and solve tomorrow's grand challenges.

Ellis Rubinstein
President & CEO
The New York Academy of Sciences

INTRODUCTION

Science and technology alone cannot solve the manifold crises that threaten our world, but neither can we face the future without them. Addressing climate change, feeding a burgeoning world population, creating jobs, and growing the world economy all depend on a global population well-educated in science, technology, engineering, and math (STEM). And 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. Millions of positions that require STEM skills remain unfilled in both emerging and developed countries.

It would be easy to blame schools and universities for not educating enough STEM students, but the problem is more complex. While there are greater numbers of STEM graduates worldwide than ever before, STEM jobs continue to go unfilled. Resolving this STEM paradox depends not only on educators and schools, but it requires a larger, more comprehensive solution: an ecosystem of government policies, business incentives, and cultural attitudes that creates the necessary circumstances for students to seek, acquire, and employ STEM skills.

A strong STEM ecosystem encourages schools, employers, and nonprofits to work together to ensure that students graduate with both the technical and personal professional skills they need. It depends on governments to incentivize companies to invest in innovation and create promising new job opportunities for these graduates. And it fosters a mentorship culture that infuses society with an understanding of the importance and opportunity that lies within STEM careers for people from all backgrounds. Only through cross-sector collaboration can a strong STEM ecosystem align the skills and ambitions of graduates with the jobs of tomorrow and the solutions to society's growing needs.

Different countries have excelled in certain elements of this ecosystem, but very few have fully developed all components. Germany, the United States, and the United Kingdom have built world-class STEM educational programs, but struggle to match the skills they teach with the needs of their employers. China, India, and Brazil produce a rapidly growing number of STEM graduates each year, but lack sufficient job opportunities to employ them. The governments of Rwanda and Vietnam have enacted promising policies to spur private sector STEM investment, but often lose their best and brightest students to employers from more highly developed economies. The STEM paradox is present across developed and emerging nations, and solving it is truly a global challenge.

A new international cross-sector discourse will therefore be essential to achieve the full potential of STEM talent for human and global development. Each country must draw on the elements

that others have already proven successful in order to assemble its own ecosystem. At the same time, governments, businesses, schools and nonprofits around the world must find a shared vision to align their efforts in mutually reinforcing ways.

This paper is intended to initiate such a discourse. It describes the global STEM paradox, and offers a new framework as a starting point for building a strong STEM ecosystem. The research for this work consisted of a literature review of more than 50 reports, interviews with more than a dozen leading experts in industry, government and academia, and expert reviewers who commented on our conclusions. This paper offers a consensus view of the steps that will be required to cultivate the next generation of global STEM leaders.

> A new international cross-sector discourse is essential to achieve the full potential of STEM talent for human and global development."

THE STEM PARADOX

The crippling shortage of STEM professionals in most countries around the world threatens to undermine economic growth and hold back the scientific advances needed to meet the world's most urgent challenges. In Sub-Saharan Africa alone, 2.5 million more engineers are needed to address the continent's gravest development problems.[1] And in the United States, company recruiters regularly report that they cannot fill the 75 percent of occupations that will require middle- or high-level STEM skills by 2018.[2] Heads of state and CEOs are increasingly vocal about the existence of a STEM crisis. Yet, paradoxically, the number of STEM graduates worldwide increases every year.[3,4] If every STEM graduate took every open position, the shortage would evaporate. This paradox continues into specific fields and skill levels. Many countries overproduce PhD-level students, for instance, and don't produce enough technicians to fill the abundance of vacant technical positions. Additionally, many STEM graduates across degree levels lack basic personal professional skills such as teamwork, communication, and problem solving. And despite widespread interest among young students in STEM gaming and science toys, that enthusiasm is often dampened by the boring rote learning forced on them in the classroom.

FOUR REASONS, IN PARTICULAR, ACCOUNT FOR THIS PARADOX:

Shortage of Graduates with Soft Skills. The frequent emphasis on rote learning and memorization in STEM subjects often results in graduates who struggle to apply the concepts they learned to the real-life challenges they face in the workplace. Students often graduate uninspired to pursue STEM careers or without the complementary soft skills in communication, critical thinking, and teamwork necessary for successful employment.[5] In India, for instance, employers report serious workforce shortages in engineering due to graduates consistently lacking interpersonal and critical thinking skills.[6]

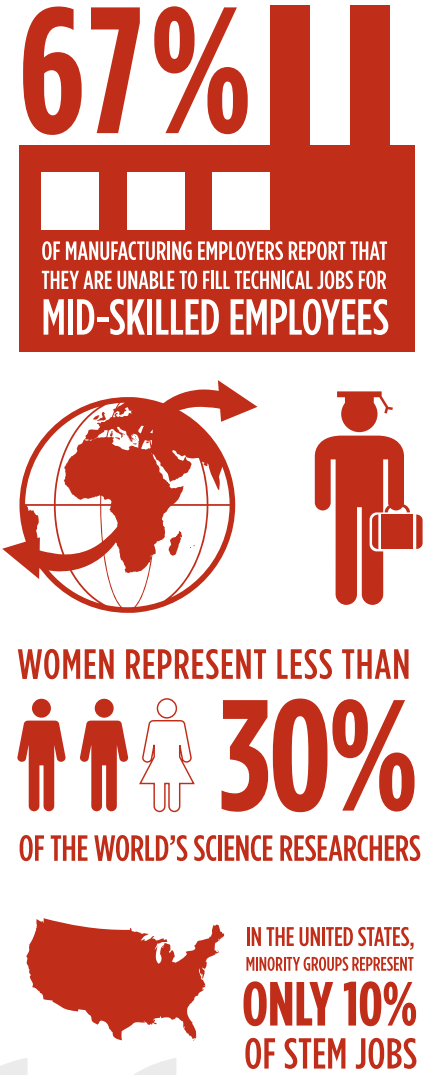
Lack of Qualified Technicians. The education system in most countries is insufficiently aligned with industry to develop student skills and aspirations that meet employer needs. Many of the unfilled positions require mid-level skills, yet universities often propel students to higher-level courses that leave them overqualified for the jobs that are available. Businesses regularly cite technicians as the number one most difficult job to fill.[7] In the United States, for instance, 67 percent

of manufacturing employers report that they are unable to fill technical jobs with mid-skilled employees.[8]

Loss of High-Skilled Workers. Accenture Institute for High Performance, in a recent report, points out that despite a "global abundance of talent,"[9] there is a mismatch between the location of most STEM graduates in emerging markets and the opportunities available in developed economies.[10] Countries across sub-Saharan Africa and the Caribbean, in particular, are losing many of their best and brightest workers. African countries lose 20,000 skilled professionals to the developed world each year[11] and, as of 2011, one in every nine Africans with a graduate degree lives outside the continent.[12] Likewise, ninety percent of skilled workers in Caribbean nations leave to pursue opportunities in other countries.[13] The implications of this "brain drain" are far reaching. Not only has the country lost talent that is essential to economic, political, and social progress, but fewer qualified graduates are available to teach and mentor future generations.

Untapped Pools of Talent. Women, rural populations, minority ethnic groups, lower socio-economic classes and other marginalized groups are acutely underrepresented in STEM fields in most developed and developing countries. Women, for instance, represent just 30 percent of the world's science researchers.[14] Ethnic minorities are similarly underrepresented. In the United States, for example, an equal proportion of minority and non-minority students express intent to study STEM subjects when they enter university, but minority groups represent only 10 percent of the STEM workforce.[15] This lack of participation of underrepresented or disadvantaged groups in STEM fields not only limits gender and income equality, but also impedes innovation and economic advancement as large swaths of talent are underutilized.

Together, these challenges create a self-reinforcing global cycle that is difficult to break. The loss of top talent in emerging markets diminishes the pool of teachers and mentors who can convey the interpersonal and critical thinking skills students need while making it harder for local technology and science-based industries to grow. Without these industries, STEM employment opportunities



> Many in rural India are practicing science and technology every day, but the challenge is how to get them into the mainstream STEM workforce."
>
> **-RAGHAV NARSALAY, India Lead, Accenture Institute for High Performance**

> A strong ecosystem allows a single vision of success at both regional and global levels."

remain scarce, reinforcing the incentives for talented graduates to emigrate. Educational pathways poorly matched with employment opportunities discourage STEM graduates from taking the STEM jobs available. This further encourages companies in developed markets to draw talent from beyond their borders. Meanwhile marginalized groups are denied access to mid-level skilled jobs, contributing to unemployment and diminishing economic growth. And the skewed pool of graduates brings less diversity of thought and ambition to drive innovation and spur the formation of new enterprises that can advance scientific knowledge and help meet society's needs.

The migration of talent, globalization of markets, and international nature of scientific research makes the STEM challenge a truly global one. Although many solutions must be implemented at regional or national levels, growing interdependency of the global economy means that the the STEM challenge cannot be solved on a country-by-country basis.

Encouraging more students to seek STEM degrees, often described as the obvious solution, does nothing to guarantee that they will leave school with the right skills and opportunities. A strong ecosystem involving the efforts of governments, schools, and businesses will help address the challenges that underpin the STEM paradox. Very few countries in the world have managed to create such an ecosystem within their own borders, but those that have, such as South Korea, Vietnam, Israel, and Singapore, have achieved astonishingly rapid social and economic progress (see sidebar on South Korea[16,17,18,19,20]). Many other countries have developed outstanding examples of one or two dimensions of the necessary ecosystem, but without all of the pieces in place, they have not achieved the same degree of progress.

A new global conversation is essential to enable countries to learn from each other what works. Each country must create a strong national STEM ecosystem to resolve its own variation of the STEM paradox. At the same time, countries must coordinate the key elements of a global STEM ecosystem across borders. The global economy and the well-being of individuals and communities depend on the success of these efforts at both the national and global levels.

BUILDING A STRONG STEM ECOSYSTEM

Research reinforces what many experts agree are the three essential practices required to build a strong STEM ecosystem:

1. Government policies that incentivize companies to invest in innovation and scientific research to create promising job opportunities for STEM graduates;
2. A strong education system that combines classroom learning with real-world experiences to provide students with both the technical and personal professional skills they need to succeed; and
3. A thriving STEM culture that infuses the entire population with an understanding of the importance and opportunity that lies within STEM.

Many elements of this ecosystem mirror those developed through decades of research on "innovation ecosystems." Innovation is, after all, at the root of scientific and technological advances, and the creation of new STEM jobs depends on the successful commercialization of those

CASE IN POINT: SOUTH KOREA'S ADVANCEMENT THROUGH STEM

South Korea is often cited as one of the most successful stories of economic development in recent history. In just 50 years, the nation transformed from a war-torn, developing country into one of the wealthiest economies in Asia and the world, increasing its GDP per capita from $92 USD in 1961 to $26 thousand USD in 2013. The Korean government has concluded that the country's competitiveness in science and technology has contributed to Korea's achievement of a globally recognized higher status. **To incentivize STEM innovation and growth** in the 1990s, the government rapidly liberalized its FDI policies, resulting in Korea becoming Asia's second-most favored investment destination. More recently, the government has increased its spend on R&D, invested in over 100 regional innovation centers and technology parks, and provided tax incentives to encourage innovation in priority industries. **A strong STEM education system** has supported this growth, resulting in enrollment rates that are among the highest in the world, and South Korea being ranked in the top ten of international student assessments. The number of schools for talented students in science has increased and, encouragingly, the majority of students plan to pursue STEM academic and professional careers after graduating. Strong collaboration between schools and industry also helps to ensure students graduate with relevant skills for the workplace. Hanyang University, for instance, is creating a software course in partnership with Samsung Electronics. Supporting the STEM ecosystem is **an inspiring STEM culture.** Koreans consider science and technology as the most important job sector for the development of society and parents are very supportive of their children seeking to study or work in STEM areas. To further encourage students to focus on STEM, new hands-on science educational programs are providing students with opportunities to make field trips overseas to the high-technology sites such as CERN. Likewise, domestic companies such as Hyundai, use their social responsibility budget to run junior engineering classes, and inspire a passion for STEM through TV campaigns emphasizing that "science is the basis of a nation". Although the Republic of Korea still faces challenges, such as low participation of women in STEM, the country's rapid economic advancement illustrates the power of a dynamic and comprehensive STEM ecosystem from which other countries can learn.

advances. Just like success in STEM, consistent success in innovation depends on a tightly linked set of financial, commercial, and educational factors. The STEM and innovation ecosystems both depend on government policies that incentivize companies to take risk and invest in research and innovation. Both also require robust institutes of higher education.[21] Yet the two ecosystems are not identical. A STEM ecosystem focuses significantly more on primary and secondary education, the development of workplace readiness and interpersonal professional skills, filling mid-skilled jobs needed by older existing technologies, and on cultural factors that influence individual career choices.

Below is an examination of how different countries have achieved success in the three key practices of a strong STEM ecosystem. Each country is in a different place on the continuum of ecosystem development. Some challenges are more prevalent in developed countries and other challenges exist primarily in emerging markets. Our

hope is that each country seeks to learn what it needs from those who have succeeded and teach what it knows to those who are still struggling.

1. INCENTIVIZING STEM INNOVATION AND GROWTH

Governments must pursue a comprehensive STEM policy agenda that incentivizes companies to invest in research and innovation. Such an agenda can create new job opportunities for STEM graduates, grow the economy, and accelerate scientific progress. South Korea, as highlighted, is a powerful example of a country that has realized rapid economic growth through government policies that promote a comprehensive STEM industrial strategy.[22] The government's goal is to create 640,000 new jobs and have R&D contribute to 40 percent of its economic growth by 2017. To accomplish this, Korea's STEM strategy has prioritized investments in energy, environment, information communication technologies (ICT), and healthcare.[23] This has created a wealth of STEM job opportunities that successfully attract and retain STEM professionals.[24]

Malaysia has similarly evolved its policy mix to attract Foreign Direct Investment (FDI) and strengthen its STEM industries. Enacting enforceable intellectual property (IP) policies and fiscal incentives have changed Malaysia, in just two decades, from an economy primarily based on agricultural exports to one focused on higher-value electronic exports (see sidebar on Malaysia below[25,26,27]). In 2010, Malaysia successfully joined the United States and Sweden in the top 10 countries of the IMD World Competitiveness Index.[28]

Policies must be targeted at specific sectors that fit the country's competitive advantages. In 2003, the President of Rwanda committed to building an economy based on science, technology, and innovation, and making Rwanda a technology hub for sub-Saharan Africa (see sidebar on Rwanda below[29,30,31,32]). Realizing that the country cannot succeed without embracing its rural roots, President Kagame's strategy includes specific goals to enhance opportunities for growth in non-urban areas. These include programs such as growing food-processing industries to help generate off-farm income for farmers. In doing so, Kagame aims to increase access to STEM careers for the entire workforce and build a robust pipeline of qualified professionals for both mid- and high-skilled jobs.[33] In fact, Rwanda has achieved significant success in pursuing this strategy. GDP grew at an annual average of 7.5 percent between 2004-2009 (compared to 5.6 percent across Africa[34]) and Foreign Direct Investment increased almost 15-fold between 2005-2008.

Other countries have incentivized domestic entrepreneurship by providing seed funding to small and medium enterprises (SMEs). Germany, the United Kingdom, China, and Israel represent just a few that have employed such policies. The

> Today, Africa faces the best opportunity for growth in its past 30 years. To sustain this growth, the continent needs to harness science and technology, integrate Africa into the global market, and transform the economies for fierce competition in a world fueled by information and driven by knowledge."
>
> **- RWANDA PRESIDENT PAUL KAGAME, 2007**

success of Israel's thriving ICT sector, for instance, is due in large part to the government financing commercial R&D since the early 1990s.[35] This support has provided innovative SMEs the funds needed to invest in new technologies when the risk is too large for banks to undertake. As of 2011, Israel's ICT sector accounted for approximately 20 percent of total industrial output and 9 percent of business sector employment.[36]

Governments must continually adjust and refine their STEM strategy and policies to ensure continued progress in line with its evolving STEM ecosystem. This applies to developed nations as much as emerging and developing economies. The United Kingdom government, for instance, has formed collaborative partnerships with corporations in each of its eleven prioritized industries. As part of the collaboration, the government is working with businesses to help develop a STEM workforce with the skills they need by co-investing in colleges and financing training programs. The partners have created a £100 million per year joint government-industry fund that will support projects that grow skills in key industries, such as a manufacturing training center to develop cutting edge skills in advanced engineering. Introduced in late 2012, the direct impact of the strategy on the ecosystem is pending, but a concerted focus on these sectors has already spurred greater investment from multinational corporations. Siemens, for example, announced that they will build new wind turbine production facilities, creating up to 1,000 jobs and providing clear opportunities for UK suppliers.[37]

At the same time, countries must begin to look beyond their own borders to learn from the best practices of other countries for how to effectively incentivize STEM innovation and growth. The workforce, innovations, and benefits from STEM are global in nature and require the development of a robust global appreciation for the importance of STEM knowledge. The Global STEM States' nascent collaboration of twenty industry, academic, and government stakeholders offers one promising platform. Launched in 2013, Global STEM State members span country economies and regions, including the United States, Australia, Malaysia, Canada, United Arab Emirates, China, India, Russia, Germany, South Africa, Tanzania, and Brazil. Each member acts as a regional STEM hub in order to promote the importance of STEM within their region. Through collaboration, the initiative ensures

> We often see developing countries that want to develop science and technology sectors, but they don't have economic strategies that are connected."
>
> **- PROFESSOR JEFFREY GOSS, Associate Vice Provost, Arizona State University; Director of Vietnam Higher Engineering Education Alliance**

TACTICS: INCENTIVIZING STEM INNOVATION AND GROWTH

1. Identify and invest in priority STEM industries most relevant to national competitive advantage.

2. Develop a robust STEM strategy with policies that support priority industries through seed funding, IP protection, and research.

3. Evaluate and refine the STEM strategy and approach in line with evolving national and regional needs.

4. Connect with the global community to identify, share, and strengthen best practices.

CASE IN POINT: MALAYSIA'S PROGRESS TOWARD A KNOWLEDGE-BASED ECONOMY

Malaysia's quest to become a knowledge-based economy by 2020 is centered on building a strong STEM ecosystem. In the late 1980s, the national strategy shifted from focusing on agriculture to emphasizing ICT, manufacturing, and, more recently, high-tech pharmaceutical and biotechnology industries. Malaysia's business environment is increasingly vibrant, catalyzed by the government **incentivizing STEM innovation and growth** through its market-driven policies and business friendly practices. Malaysia's Multimedia Super Corridor (MSC), for instance, offers tax breaks and incentives to firms who headquarter in the country in a bid to attract multinational corporations, such as BMW and Ericsson. Realizing that this transformation requires a completely new set of skills, Malaysia has **invested heavily in building a strong STEM education system.** Expansion of the higher education system has resulted in a 145 percent increase of students enrolling in science and technology subjects between 1997 and 2005. Even with these advances, Malaysian graduates are still often considered not "work ready" and businesses struggle to fill positions. This paradox is hindering the country's full potential for economic growth. Underpinning Malaysia's progress toward a knowledge-based economy is its effort to **foster an inspiring STEM culture.** The Malaysian Academy of Sciences, for example, aims to bring science to the general population through engaging programs such as the Young Scientists Network-ASM and the National Science Challenge (NSC). Public research institutions are also contributing to the creation of an inspiring STEM culture by formalizing mentorship programs that enhance work environments and encourage persistence in STEM fields.

members can share best practices that will help them align STEM education with the human resource needs of their region to enable strong and sustainable economic and social development.[38]

2. BUILDING A STRONG STEM EDUCATION SYSTEM

A strong STEM ecosystem depends on an interdisciplinary education system that is closely aligned with workforce needs. No longer can the education system be defined just as schools and universities; a student's education must be reframed to include time both inside and outside of school, intergenerational learning within the family and community, and experiences students have interacting with real world problems.

Consider Germany's world-renowned vocational pathways. The government, educators, and industry work closely together to forecast future mid-skilled and technical workforce needs. Businesses then partner with government-regulated vocational schools to make apprenticeship opportunities directly available to students. Students are able to combine classroom learning with hands-on practice in the workplace, such as at Siemens' Apprenticeships through the Europeans Programme, which provides students with 3.5 years of intensive training and apprenticeship in mechatronics and electrical engineering. Although the system is more than 100 years old,[39] the tight linkage between educators and industry has kept the apprenticeships dynamic and current with contemporary technology.

Many countries look to the German model to inform the design of their vocational education system. South Korea, for instance, is drawing on this approach to address a deficit in mid-skilled workers and combat a deeply embedded cultural

bias against vocational careers across the country. The South Korean Government launched Meister Schools, providing technical training, apprenticeships, and personal professional skill development in fields that align with their stated priority industries. To strengthen the education-to-employment link, the schools have partnered directly with over 1,300 companies that are looking for mid-skilled graduates.[40] Although the initiative is relatively new, there is already evidence of increased employment and a shift in attitudes towards vocational career paths.[41,42]

Schools can also partner directly with business at the city and regional levels to align education with local employment opportunities. In the United States, for instance, the Pathways in Technology Early College High Schools (P-Tech) program, led by IBM, emphasizes technology-based curriculum for high school and early-college students.[43] The program's emphasis is on mastery through internship and training opportunities provided by IBM and other companies. It provides a personalized pathway for marginalized students who are underrepresented in college and in the IT industry, encouraging them to persist and succeed.[44] P-Tech's first graduating class is still several years away, but early results are promising: nearly half of its students have earned college credits and nearly 100 percent are passing high school compared to the 71 percent graduation rate citywide.[45] Collaborations such as these will foster a workforce that more accurately meets employer needs and reflects the demographics of the broader population. While P-Tech first launched in New York, other states, such Illinois, Maine, Massachusetts, Missouri, and North Carolina, recognize the potential and are replicating the program in their school systems.[46] Countries should scale unique approaches to education, such as these, that more accurately reflect the skills students need to succeed in the workplace.

On-the-job apprenticeship and classroom curricula must also be supplemented by inspiring teachers and mentors who can open students' eyes to possibilities that lie within STEM careers.[47] Having access to inspiring professionals as mentors can help build these essential competencies. Students can draw on mentors from industry, government, or academia to help bring STEM theories to life. The New York Academy of Science's Afterschool STEM Mentoring Program—a large-scale program funded by the National Science Foundation and led by the Academy with the New York City Department of Youth and Community Development and the State University of New York, with nearly 100 partners—places trained graduate students and postdoctoral fellows in afterschool programs in underserved New York schools to provide mentoring and hands-on science experience. The benefits are reciprocal: graduate students receive practical experience as STEM teachers, allowing them to consider teaching as a career and learn to better communicate STEM subjects across audiences; simultaneously, students have the opportunity to experience STEM in engaging, informal settings with role models they can relate to.[48] Similarly, the Intel PhD Fellowship program builds collaboration with premier engineering and research institutions, universities, and the government to bridge the gap between academia and industry standards and promote innovation and entrepreneurship. In addition to receiving $50,000 in grant funding, fellows are assigned a well-re-

> The reality is that the entire STEM pipeline is too theoretical and didactic. This results in poorly trained workers mismatched with what big global employers are looking for."
>
> **- ERIC JOHNSON, Deputy Director of the Office of Education and Technical Lead for Higher Education and Workforce Development, USAID**

> The biggest changes are that these schools [Meister Schools] go from being the shame of the community to being the pride of it. And the students go from listless participants in their education to enthusiastic learners in it."
>
> **- LEE JU-HO, Former Minister of Education, Science, and Technology**

TACTICS: BUILDING A STRONG STEM EDUCATION SYSTEM

1. Align educational curricula and skill development with local employer needs.
2. Foster robust vocational and technical training career pathways across skill levels.
3. Build a system of internship, apprenticeship, and mentoring opportunities.
4. Offer untraditional education opportunities to reinforce in-school curricula.
5. Increase access to technology that can deliver innovative education programs.

spected Intel technical mentor to work directly with to help solve the most complex technical problems facing the industry.[49] To date, the program has reached more than 235,000 students and 4,500 faculties across 550 institutions.[50,51] As these and other programs grow in reach, companies such as Tata Consultancy Services, ARM Holding, and PepsiCo are increasingly focused on bolstering employee engagement, boosting local relationships, inspiring the next generation of employees, and building skills by incentivizing their employees to participate in mentoring programs.

While access to high quality enrichment programming and role models is key, access to basic instruction in the STEM field has traditionally been limited to teachers. The advent of online courses, and technology schools that emphasize technology as a learning tool means that more students have access to specialized instruction. The Learning Channel in South Africa is one such untraditional model where formal and information education systems align. Its vision is to support a growing learning community by providing a multi-media, holistic education solution to South Africans and communities across seven other African countries. The program utilizes television, print, Internet, and seminars to reach the broadest population possible, and ensures that the teaching methods are modern and relevant.[52] DragonBox is another innovative tech-

nology that helps demystify algebra so students can build on their understanding to learn more advanced mathematics in university or beyond. The interactive game teaches algebra's core concepts through pictures rather than numbers at the outset to give students confidence, and then transitions to more formal approaches.[53] On average, students master algebra skills in less than one hour using the DragonBox app.[54]

3. FOSTERING AN INSPIRING STEM CULTURE

An inspiring STEM culture places value on the importance of STEM and what it brings to the community; families and individuals appreciate how essential all STEM pathways are to the field, and the general public has a basic understanding of STEM and the value of a diverse STEM workforce.

Cultivating a culture that values STEM starts at an early age. In Vietnam, The First Academy (TFA) in Ho Chi Minh City offers a program dedicated to STEM in preschool. In collaboration with the Vietnamese English Language Institute (ELI) and Carnegie Mellon University, TFA has developed a STEM syllabus suitable for very young learners that uses robotics and ICT, through play and interactive technologies, to help children develop creativity and scientific thinking skills.[55] Schools such as TFA have the potential to foster passion for STEM before students are influenced by cultural biases that may lead them away from pursuing these fields, and demonstrate to parents and education professionals the need to seamlessly integrate ICT, STEM, and interactive learning environments into the school day.

Outside of the classroom, recreational activities are an important component to inspiring a passion for STEM. Zoos, museums, and science centers are amongst the most popular attractions for families and provide impactful opportunities for intergenerational learning. Popular television shows, such as "Mythbusters," continue to inspire kids to pursue STEM fields by elevating STEM professions to celebrity status. Debuted in the United States, "Mythbusters" currently airs in every region that carries Discovery Channel, as well as on free terrestrial TV in Eastern and Central Europe, Denmark, Finland, Norway, Sweden, South Africa, and Australia.[56] Similarly, in Qatar, the vastly popular "Stars of Science" reality show helps to bolster interest in science and technology and accelerates the development of the region's future innovators. Alumni of the program give back to the community through active mentoring of other innovators, speaking publically, presenting at TEDx events, and supporting the launch of startups.[57] These activities help to catalyze knowledge of and interest in STEM beyond program viewers to the entire culture of the population.

> Employers are often looking for specific technical skills but also soft skills. This is a problem for university graduates. They know about science, but not behaviors needed in the workforce."
>
> **- NICK BURNETT, Managing Director, Results for Development InstituteDevelopment, USAID**

Elevating the visibility of diverse up-and-coming professionals can also help overcome cultural biases that lead to an imbalance of women and underrepresented population in STEM fields. The Fondation L'Oreal in France, in partnership with UNESCO, promotes women in science and supports female researchers globally at all points in their careers. The program distinguishes leading scientists with the L'Oréal-UNESCO Awards and provides international fellowships to young researchers so they can widen their scope of expertise at recognized research institutions out-

> Teaching science to the very young, in early education years, helps ground them in thinking scientifically."
>
> **- TIM OATES,**
> **Group Director of Assessment Research and Development, Cambridge Assessment**

TACTICS: FOSTERING AN INSPIRING STEM CULTURE

1. Promote STEM heroes and elevate the importance of STEM professionals at home, in school, and in the media.

2. Support the development of and engagement in fun, interactive recreational STEM activities.

3. Develop public education initiatives that breakdown stereotypes about technical and vocational training.

4. Invest in STEM teaching so it becomes a more attractive career path.

5. Attract diverse demographics into STEM through mentorship and redefining STEM in the workplace.

side their home countries. By the end of 2014, more than 2,000 women scientists from over 100 countries will have benefitted from the program, and two of the L'Oréal-UNESCO Award recipients have subsequently received the Nobel Prize.[58,59]

Other promising strategies to engage women and underrepresented populations in STEM fields include ensuring they have a clear understanding of career options, redesigning the ways in which STEM is taught at university, and engaging role models to provide targeted support throughout their education and career. One such initiative that emphasizes the importance of women mentors is the U.S. Department of State's NeXXt Scholars Program, in partnership with 38 U.S. women's colleges and the New York Academy of Sciences. This initiative matches female undergraduates from the United States and Muslim-majority countries with a female STEM professional as a personal mentor. The program leverages the New York Academy of Sciences' vast membership network to provide Scholars with mentors and networking opportunities. Additionally, Scholars gain access to leadership training, internships, workshops, and research opportunities to build their skills and confidence.[60]

At the same time, an inspiring STEM culture recognizes all career paths as valuable, including vocational and technical jobs, and fosters engagement across disciplines and skill levels. South Korea's apprenticeship-focused Meister Schools, for instance, have helped to transform the perception of STEM technical professions as respected careers themselves, not just as starting places for higher-level education. In just 3 years, the number of Meister School students going straight into work instead of pursuing an advanced degree has increased from 19 to 33 percent.[61] These schools are not only helping to meet the growing need for technicians in South Korea, but also unlocking valued career opportunities for the future STEM workforce. A strong STEM culture will help normalize expectations, create a more representative and equitable workplace, and ingrain the value of STEM across the population.

CASE IN POINT: RWANDA CHOOSES STEM FOR GROWTH AND PROSPERITY

Rwanda has more recently adopted STEM as its approach to realizing growth and development. Since 2003, President Paul Kagame's government has been dedicated to **building capacity in STEM fields** with the aim of establishing Rwanda as the premier technology hub in Sub-Saharan Africa. The progress Rwanda has made over the past twenty years since its devastating genocide is remarkable, both economically and socially. Economic growth has exceeded 8 percent per annum over the past decade—well above the continent's average growth—and the under-5 mortality rate has been cut in half. Achieving progress such as these is due in part to Rwanda's dedication to fostering a strong STEM ecosystem. Rwanda's national strategy is anchored in science and technology and its **investment policies are aligned to incentivize STEM innovation and growth,** such as attracting foreign direct investment into its priority sectors (e.g., ICT). The Ministry of Education is, likewise, focused on **building a strong STEM education system** in both traditional and untraditional education pathways. They have launched continuous teacher training to boost science and math education in secondary schools, and strengthened Technical and Vocational Education and Training (TVET) programs to support the country's growing industrial sector. With an eye to long-term commitment to STEM beyond the focus of the Kagame administration, Rwanda is working on fostering an inspiring STEM culture. Romain Murenzi, former Minister of Science has stressed that a **culture of science that is accessible to everyone** is critical for basic national development. Toward this goal, Rwanda celebrates "World Science day" each year, a series of competitions to spark interest in youth for STEM, and offers programs such as Rwandan TechWomen to encourage women to pursue STEM careers through mentorship and cross-country exchange. While Rwanda is still early in its development, building a strong STEM ecosystem is helping the country make progress toward their ambitious goal to "open up the frontiers of science, technology, and research" and realize its 2020 vision for a prosperous and flourishing society.

> We need to arouse a passion in the kids we teach for the world around them. This will fuel their tenacity to continue with a difficult subject because they will understand why it is important."

- PROFESSOR DATO' DR. RAHMAH MOHAMED,
Vice Chancellor, INTI International University, Malaysia

CONCLUSION

This paper lays out a solution to the STEM paradox: a strong STEM ecosystem of government policies, business incentives, and cultural attitudes that will create the essential components for countries to realize increased economic growth and country competitiveness, and the world to benefit from solutions to global challenges.

The three sidebars highlight promising strategies. South Korea has advanced rapidly through dedicated focus and investments in STEM. It looked beyond its borders to well-established STEM ecosystems, like Germany's, to model its approach. Malaysia is currently on the path to development through STEM and is eager to learn from other countries. As such, they are early members of two global STEM organizations, Global STEM States and Global STEM Alliance. Rwanda is in the early stages of creating a strong STEM ecosystem, but has already realized economic and human progress over the last decade. Similar to South Korea and Malaysia, Rwanda collaborates with peer countries to leverage knowledge and accelerate progress. In partnership with the World Bank, Rwanda is hosting forums and partnerships to align Africa's higher education with the continent's massive and unmet demand for engineers, scientists, health professionals, and technicians.

As these cases illustrate, in today's complex and interconnected world, global, cross-sector collaboration is a critical key to resolving the STEM paradox. In issue after issue, from pandemics to climate change, and from economic development to infant mortality, the field is increasingly moving toward a new model of social change rooted in collective impact. Individual institutions, corporations, and even governments, do not have the capacity to solve global challenges by themselves. And yet working across sectors and national borders can be difficult.

As challenging and perplexing as the creation of a STEM ecosystem may seem, different countries have created successful models that, taken together, cover every aspect of the necessary ecosystem. New international cross-sector collaboration is essential to assemble these separate elements of success into the comprehensive solution each country needs to achieve the full potential of STEM for economic and social progress. Bold leadership is required, yet the reward is immense. Solving the STEM paradox will spur the social, economic, and scientific achievements that are needed to help solve the world's greatest challenges.

APPENDIX A: LIST OF INTERVIEWEES & REVIEWERS

This paper draws on the experiences and insights of education experts from corporations, government, academia, and nonprofits. The individuals listed below were generous enough to share their time in interviews conducted between June and July 2014.

James Bernard*
Global Director, Partners in Learning, Microsoft

Nicholas Burnett
Managing Director, Results for Development Institute

Lori Conlan*
Director of Postdoctoral Services, National Institutes of Health

Gabriela Gonzalez
Senior STEM Strategist, Intel Corporation

Jeffrey Goss
Associate Vice Provost, Arizona State University; Director of Vietnam Higher Engineering Education Alliance

Eric Johnson*
Deputy Director of the Office of Education and Technical Lead for Higher Education and Workforce Development, USAID

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Tim Oates
Group Director of Assessment Research and Development, Cambridge Assessments

Mark Purdy
Managing Director and Chief Economist, Accenture Institute for High Performance

Robert Thomas
Managing Director, Accenture Institute for High Performance

Andrew Zwicker
Head of Science Education at the Princeton Plasma Physics Laboratory

* Those with an asterisk also provided their expertise as a reviewer of the paper.

ENDNOTES

[1] World Bank News. "Higher Education in Science and Technology is Critical for Africa's Development," 2014.
[2] The Social Market Foundation. "In the Balance: The STEM human capital crunch," 2013. See also Manpower Survey. "Talent Shortage Survey Research Results," 2013.
[3] Brazil, China, and India have increased the number of STEM graduates from 4 million to 5 million annually over the last four years, while developed countries such as the United States, United Kingdom, and Japan have continued to produce 1 million graduates each year.
[4] Accenture Institute for High Performance. "Where Will All the STEM Talent Come From?" 2012.
[5] FSG Interviews, July 2014.
[6] World Bank. "Employability and Skill Set of Newly Graduated Engineers in India," 2011.
[7] Manpower Survey. "Talent Shortage Survey Research Results," 2013.
[8] Manufacturing Institute. "2011 Skills Gap Report," 2011.
[9] Accenture Institute for High Performance. "Where Will All the STEM Talent Come From?" 2012.
[10] Accenture Institute for High Performance. "Where Will All the STEM Talent Come From?" 2012.
[11] UNDESA and the OECD. "World Migration in Figures," October, 2013.
[12] SciDevNet. "Benefiting from Africa's brain migration," 2014.
[13] International Business Times. "Latin America Is Losing Qualified Young Workers to OECD Countries," November, 2013.
[14] UNESCO Institute for Sciences. "Women in Science: Explore the data for countries worldwide," 2014.
[15] Allen-Ramdial, S. and Campbell, A. G. "Reimagining the Pipeline: Advancing STEM Diversity, Persistence, and Success," Bioscience. 2014.
[16] South Korea Ministry of Education, Science, and Technology, "Science and Technology Strategy," 2012.
[17] OECD. "Science, Technology and Industry Outlook 2012," OECD Publishing, 2012.
[18] World Economic Forum. "The Global: Competitiveness Report 2013-2014," The Global Competitiveness and Benchmarking Network, 2013.
[19] Australian Council of Learned Academies. "Securing Australia's Future: International comparisons of Science, Technology, Engineering and Mathematics (STEM) Education Final Report, Country Profiles, Republic of Korea," 2013.
[20] Times Higher Education website. "World University Rankings 2013-14," retrieved 2014.
[21] National Science Foundation website. "The Innovation Ecosystem," retrieved 2014.
[22] South Korea Ministry of Education, Science, and Technology, "Science and Technology Strategy," 2012.
[23] British Embassy Seoul, UKTI Digital, for UK Trade & Investment. "South Korea: New Basic Plan for Science and Technology," July, 2013.
[24] British Embassy Seoul, UKTI Digital, for UK Trade & Investment. "South Korea: New Basic Plan for Science and Technology," July, 2013.
[25] Natalie Day and Amran bin Muhammad. "Malaysia: The Atlas of Islamic-World Science and Innovation. Country Case Study No.1," 2011.
[26] World Economic Forum. "The Global: Competitiveness Report 2013-2014," 2013.
[27] National Science and Research Council, Malaysia. "PRA Performance Evaluation: Unlocking Vast Potentials, Fast-Tracking the Future," 2013.
[28] IMD Business School, IMD: Lausanne, Switzerland. "World Competitiveness Yearbook Results 2010," 2010.

[29] Tony Blair, The Guardian. "20 years after the genocide, Rwanda is a beacon of hope," April 2014.
[30] JICA website. "Strengthening Education and Training in Science and Technology," retrieved 2014.
[31] Science Advice Conference, August 2014. Tweet, Twitter from Science and TechnologyAU, @ScienceAU.
[32] TechWomen website. "Emerging Leaders 2013, Rwanda," retrieved 2014.
[33] World Bank. "Building Science, Technology, and Innovation Capacity in Rwanda," 2008.
[34] African Economic Outlook. "Real GDP Growth Rates, 2004-2014," 2014.
[35] Israel Business Connection, Office of the Chief Scientist (OCS), Ministry of Industry, Trade and Labor, 2013.
[36] Iian Moss, OECD Observer. "Start-up Nation: An innovation Story," 2011.
[37] United Kingdom Government press release. "Industrial Strategy: Government and industry in partnership. Progress report," April, 2014.
[38] Global STEM States Website. "About Us," retrieved 2014.
[39] Cedefop Panorama series. "Towards a history of vocational education and training (VET) in Europe in a comparative perspective," October 2002.
[40] Michael Horn, Forbes. "Meister of Korean School Reform: A Conversation with Lee Ju-Ho," 2014.
[41] McKinsey. "Education to Employment: Designing a System that Works Report," 2013.
[42] Michael Horn, Forbes. "Meister of Korean School Reform: A Conversation with Lee Ju-Ho," 2014.
[43] P-Tech NYC website. "About Us," retrieved 2014.
[44] The Aspen Institute website. "IBM P-Tech: Model of Success: Pathways in Technology Early College High School (P-TECH)," retrieved 2014.
[45] Next City website. "IBM's Department of Education," August 2013.
[46] Educator Innovator website. "P-Tech Schools: The Remaking of Career, Technical Education," August 2014.
[47] StriveTogether. "Beyond Content: Incorporating Social and Emotional Learning into the Strive Framework," August 2013.
[48] The New York Academy of Sciences. "Empowering the Next Generation of Scientific Innovators: The Global STEM Alliance," 2014.
[49] Stanford School of Medicine. "Intel Corporation 2014-2015 PhD Fellowship Program," 2014.
[50] The Times of India. "Intel India offers Rs 5.7 lakh PhD fellowship programme," March 2014.
[51] E-Pao: Now the World Knows News Website. "Intel India Announces the Intel PhD Fellowship Program - Aimed at boosting Academic Research in India by supporting deserving PhD Students," 2014.
[52] Fikile Nkambulo, Science in Africa. "The Learning Channel An Innovative Approach to Educating South Africa," retrieved 2014.
[53] DragonBox website. "About," retrieved 2014.
[54] Forbes. "It Only Takes About 42 Minutes To Learn Algebra With Video Games," July 2013.
[55] The First Academy Website. "STEM Education," 2013.
[56] RealScreen. "The stuff of myth: "MythBusters" celebrates 10 years on air," February 2013.
[57] Newswire. "Stars of Science Returns to Showcase Young Arab Innovators in its Upcoming Sixth Season on MBC4," September 2014.
[58] Fondation L'Oreal website. "The For Women in Science Program," retrieved 2014.
[59] UNESCO website. "Gender and Science: For Women in Science Programme." Retrieved 2014.
[60] US Department of State website. "NeXXt Scholars Program Factsheet," December 2013.
[61] McKinsey. "Education to Employment: Designing a System that Works Report," 2013.

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The GSA is the first global initiative of more than 70 governments, corporations, educational institutions, and nongovernmental organizations in more than 50 countries working with the New York Academy of Sciences to solve the STEM paradox. Together we are committed to reach 1 million aspiring students in 100 countries by 2020. You can join us.

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