International STEM Achievement: Not a Zero-Sum Game

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It seems that every few years, science, technology, engineering and mathematics (STEM) educational policymakers ring alarm bells. Educational experts from a multitude of different nations are concerned with STEM education in their homelands, because they fear their students are in a state of decline when it comes to science and mathematics achievement. Projecting decades forward, they panic about how this lack of achievement will translate into a reduction in STEM productivity and a corresponding decrease in their own national prominence in the world. They double down on their efforts in STEM education, but too frequently their efforts result in educators spending the limited classroom time that is dedicated to science on preparing students to take standardized tests.

However, international STEM achievement is not a zero-sum game in which there must be losers for there to be winners. In a global economy, STEM achievement in any nation can improve the lives of people around the world. For evidence, consider Norman Borlaug, who single-handedly saved millions of lives around the world. In the 1940s, Borlaug, an agriculturalist, experimented in Mexico with special varieties of hardy wheat that would ultimately produce much greater crop yields. In the 1960s, experts who anticipated massive famines and starvation in Asia and the Middle East due to a population explosion recruited Borlaug to implement his innovative crop techniques, and the result was astonishing. Using his methods, crop yields skyrocketed, feeding millions of people who otherwise would have starved. At one time, agriculturalists estimated that Borlaug's wheat produced approximately 23% of the world's calories. Borlaug was awarded the Nobel Prize in1970 for his accomplishment (ScienceHeroes.com, n.d.).

The salient message from Borlaug's story is that all of the world's peoples stand to benefit when any scientist from any nation excels; it's a win-win situation, and yet we continue to consider it a competition, focusing only on the development of our own students and fearing that others may get ahead of them.

International STEM Educational Achievement

The very notion of STEM achievement has become muddled because we frequently confuse and conflate two different constructs: *STEM educational achievement* and *STEM creative productivity*, or the ability of individuals to use their talents to produce something creative or original in their fields (Renzulli, 1992). Second, we have not fully come to terms with two

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influential factors that will likely impact future STEM outcomes across the planet: changes in which nations are the most productive in STEM, and the extreme influence of poverty on both educational achievement and productivity. To understand these issues, it may be helpful to consider the following questions:

1. What do we know about STEM *educational achievement* internationally; and,
2. What do we know about STEM post-graduate *creative productivity* internationally?

We must also consider whether STEM educational achievement leads to STEM creativity and productivity, as well as the role that poverty plays in determining educational and occupational outcomes for students. By taking a more nuanced view of these issues, we may begin to better understand the place of individual nations in terms of STEM education and achievement. We may also argue that we should begin to consider global achievement rather than national achievement in order to prepare all of our students to take their places in a changing global STEM landscape.

Turning to the first question regarding what we know about STEM educational achievement, researchers from different nations frequently use various types of metrics to understand the impact of educational systems on students, especially in the teaching of science and mathematics. To understand international outcomes related to this issue, we must consider two key indicators of educational achievement: international test scores and numbers of advanced STEM degrees.

International Test Scores

Practitioners and researchers use two international assessments in STEM to measure educational achievement: the Trends in International Mathematics and Science Study (TIMSS), and the Program for International Student Assessment (PISA). However, each of these assessments is influenced by factors external to the classroom, including poverty, stability, and home life.

TIMSS

In 2011, TIMSS measured science and math outcomes in 63 countries and 14 benchmarking entities, or sub-components of nations (e.g., England is a separate benchmarking entity within Great Britain). TIMSS assesses both content knowledge and cognitive processes together—students are required to use cognitive processes to apply facts (content knowledge) to explain a phenomenon. For example, a typical fourth-grade-level TIMSS question might be to explain why plants do not need to take in food, but humans do. TIMSS also assesses the integration of inquiry-related practices.

Results for the 2011 TIMSS assessment indicated that East Asian students, particularly students in Korea and Singapore, scored highest marks at both the fourth and eighth grade levels. The United States ranked in seventh place in fourth grade and 10th place in eighth grade, achieving significantly higher scores at 547 (fourth grade) and 525 (eighth grade) than the scale's middle score, 500. It is interesting to note the distribution of scores in the top-ranking and lowest-ranking nations, however. In fourth grade, the distribution of scores is much wider within each nation scoring *below* the mid-point, such as Morocco and Yemen, than within nations scoring *above* the midpoint, such as Korea and Singapore. This wider distribution of scores suggests broader gaps in lower scoring nations between sectors of the student population. Of course, there is enormous diversity among these nations in terms of economic advantages, geography, and population. In fact, there appears to be an association between a number of factors external to the classroom and student achievement on the TIMSS in science. Parental income and education, as well as resources at home, were reported to play a significant role in test results, as were school-related factors such as teacher preparation, engagement with science, and even school safety (TIMSS and PIRLS, 2013). Specifically, students coming from nations and homes that place an emphasis on science, and who have well-prepared teachers and an abundance of resources, tend to do better on the TIMSS.

PISA

PISA is one of the most respected of the international assessments. Given every four years to 15-year-old students, PISA assesses literacy in reading, mathematics, and science. The results of the 2012 administration have been recently released (National Center for Education Statistics, 2013), and similar to the TIMSS results, PISA outcomes indicate that in every nation there exists an achievement gap between advantaged and disadvantaged. The size of this gap varies from nation to nation, but what is interesting is that the disparities themselves are persistent, and more similar to each other than they are different (Carnoy & Rothstein, 2013). Even in developed countries such as the United States, poverty plays a role in achievement. In a 2013 study from Martin Carnoy and Richard Rothstein, the researchers found that the gap between U.S. students and those from the highest-achieving countries on the PISA assessment would be cut in half in reading, and by at least a third in math, if socioeconomic differences were taken into account. However, a few nations are making progress in closing these gaps. For example, the PISA achievement of disadvantaged students in the U.S. has been rising rapidly over time, while achievement of disadvantaged students in countries to which the United States is frequently unfavorably compared—Canada, Finland, and Korea, for example—has been falling rapidly (Carnoy & Rothstein, 2013).

Advanced Degrees in STEM

A second indicator of educational quality in STEM is the number of students who enter the academic pipeline by pursuing PhDs, and in this area, certain nations are producing graduates in record numbers. The number of science PhDs earned in STEM overall grew worldwide by 40% from 1998 to 2008 (Cyranoski, Gilbert, Ledford, Nayar & Yahia, 2011). Indeed, many of the established member nations of the Organisation for Economic Cooperation and Development (OECD) have produced a surplus of PhDs that threatens to outpace jobs available in STEM, especially academic jobs. In Japan, the United States, Germany, and Poland, for example, the number of PhDs earned has outpaced jobs available in the academic market. However, non-OECD nations may experience a dearth of academics who will focus on research: for example, Egypt is struggling to produce more PhDs, and these degrees are often not gateways into academic research careers; rather, students in Egypt frequently use these degrees to enter civil service careers, and in Egypt, graduates frequently enter private industry, not academia (Cyranoski et al., 2011). Careers in civil service may be personally rewarding, but they are not likely to contribute to STEM innovations in the form of research publications, patents, and trademarks.

Conclusions Regarding STEM Educational Achievement

To answer the first question, “What do we know about STEM *educational achievement* internationally?” we must begin by acknowledging the enormous impact that poverty and factors external to the classroom have on educational outcomes. Students from impoverished countries generally score far worse than students from advantaged countries on international assessments, and they are not as likely to pursue more advanced education or to work in research-related fields. What if the next great thinker—the next Borlaug, Hawking, or Curie—struggles to find food and shelter in one of these countries? What if he or she has never attended a day of school? What is the extent of this loss to the child? To our world?

Changing Global Patterns of Creative Productivity in STEM

Another concern is that, even with so much emphasis placed on students' test scores, it is not evident that the outcomes of the assessments relate in a meaningful way to STEM productivity, or the ability of these students to grow up and make meaningful, innovative contributions to STEM fields. Some nations, such as Korea, whose students achieve top scores on international STEM assessments, do not produce innovations at the same rate as moderately scoring nations. For example, in 2012 the United States produced 23.1% and 6% of the world's patents and trademarks respectively, compared with 8% and <1% for the Republic of Korea. Two moderately scoring countries, Turkey and China, have experienced the greatest growth in patent submissions (World Intellectual Property Organization, 2013).

The reasons for this limited correlation between test scores and STEM productivity vary. One reason, previously discussed, is the likely influence of poverty. Another reason is likely that these tests measure content knowledge, which is very different from the type of creativity required for innovation. To understand this phenomenon further, it is necessary to consider patterns of creative productivity in STEM outputs.

One of the major goals of STEM education is the cultivation of STEM interest and talent in each nation's young people, in the hopes that they will eventually go on to what Renzulli (1992) terms *creative productivity*, or the ability of individuals to use their talents and abilities to produce something creative or original in their fields. This creative productivity may be measured in a number of different ways, including investment in research and development, as well as numbers of academic papers and patents—and global changes are occurring in this area, as creative productivity disperses across the globe.

Investment in Research and Development

Total investment in research and development varies across countries and economies. However, the 34 OECD member nations that are located primarily in Europe and North American have in previous decades dominated research and development. Sources of investment include business, government, and higher education; as the financial health of these institutions waxes and wanes across economic cycles, so does funding for research and development. In Europe, investment grew by 10% from 2007-2011, while in the United States, investment remains stagnant, mostly due to a decrease in funding from businesses. In Japan, investment has declined. Some nations that are not members of OECD but maintain a partnership status are on the rise. For example, partner-nation China is experiencing tremendous growth- investment has doubled since 2007 (OECD, 2013). Foreign direct investment (FDI), or investment from other countries that may afford recipient nations opportunities to fund additional research and development, is also moving east. China, for example, increased its inflow of FDI five-fold from 2008 to 2011, and is now the largest recipient of FDI (OECD, 2013).

STEM Research

The dissemination of innovative ideas through the publication of academic papers is yet another way to measure and compare STEM productivity by nation. Non-OECD nations, which have not traditionally been considered publishers of research, are also playing a larger role than in previous decades. For example, China, which again is an OECD partner (but not a member) nation, produced the second-largest number of STEM-related academic papers after the United States, which remains the top producer. Many of these papers were written by researchers who first collaborated with scholars in OECD nations, typically in the United States. Increasingly, rather than remain in the United States, these researchers are returning to their own countries (OECD, 2013). The fact that they are returning make sense, because according to World University Rankings (2014), although most top-rated universities (30 out of 50) are still located in the United States, for the first time two are located in places outside the United States, such as in the non-OECD nation, China (Tsinghua University). However, these universities appear to be experiencing a learning curve in academic publishing, evidenced by the fact that these papers are not always as influential in their fields; when adjusted for number of citations, China lags behind most OECD nations (OECD, 2013).

Patents in STEM

An additional indicator of a nation's strength in the area of STEM is the number of patents issued each year. A total of 20 patenting regions exist, and in this regard, the U.S. still holds the dominant position. However, the percentage of patents held by the U.S. has declined over time. For example, in 1963, the U.S. produced 82% of all patents worldwide; in 2013, it produced 49% (U.S. Patent and Trademark Office, 2013). In terms of patents in knowledge-intensive industries such as biotechnology, nanotechnology, and the communication industries, there appear to be geographical hotspots that include the U.S, Japan, China, and a number of other nations (OECD, 2013). However, in these industries, Japan's patents have increased from 1998 to 2008 - up 17% to 29%, and China also increased its patents in the same period in these areas, particular in biotechnology and nanotechnology, while the U.S. declined from 50% to 34% (OECD, 2013; U.S. Patent and Trademark Office, 2013).

Whereas the United States and Europe once dominated worldwide STEM achievement, a trend appears to be emerging that indicates productivity will be more of a globally-based phenomenon. China in particular is rapidly ramping up in terms of STEM productivity, and in many ways this is not surprising, because emerging technologies that make it possible to collaborate and communicate as never before may have helped level the playing field, making it possible for researchers from different nations to work together (Brown, Lauder, & Ashton, 2008). And in this case, it may truly be a case of "a rising tide lifts all boats," for STEM innovation is likely to bring with it a boost to each nation's economy, spurring future innovation and funding for research.

Winners and Losers

Is there a problem with STEM education and future STEM productivity? The answer to this question may be that it depends on your definition of *problem*. In the 20th century, we witnessed scientific marvels unfold at an unprecedented pace. The century dawned without flight, electric lights, modern appliances, automobiles, or telephones. Before its end, we had walked on the moon, worked with laptop computers, and thought nothing of flying across oceans. The question of the future concerns all of us, and we worry that declining test scores for our particular nation may mean that we are concerned that our own students will not be capable of producing these wonders. We wonder which nations will be "winners" and which will be "losers" in terms of STEM—which nation or nations will dominate the world to produce the next generation of scientific advances.

As previously stated, the question under consideration actually has two parts: STEM educational achievement and STEM creative productivity. In terms of STEM educational achievement, we focus frequently on student test scores as predictors of a nation's ability to remain competitive in the STEM workforce. However, this was not always the case, and some researchers (e.g., Levin, 2012) maintain a more nuanced view of the situation: test scores represent cognitive achievement and are only one metric of a nation's future productivity (National Research Council, 1984). Other metrics include cognitive traits not measured by tests, as well as non-cognitive attributes such as dispositions, personality, and motivation, and these combinations of traits play out in different ways that result in individual and nationwide achievement (Levin, 2012).

In terms of STEM creative productivity, we are beginning to see the writing on the wall: talent exists in many nations; however, the talent doesn't always exist where there is need (Craig, Thomas, Hou, & Mather, 2011). Employers who require STEM skills frequently either do not know from which nations they can recruit talent, or they may experience systemic legal or political barriers to recruitment (Craig et al., 2011). In a recent report by the OECD (2013), analysts reached three important conclusions (among others) after an extensive analysis of economic data: (a) researchers are increasingly mobile; (b) foreign consumers sustain jobs; and (c) emerging economies are playing a more important role now in science and education than ever before (pp. 13-15). These indicators emphasize the importance of collaboration between nations. Based on these facts, instead of focusing on STEM test scores, it may be more appropriate for governments to lessen governmental and organizational barriers to international cooperation and to provide high levels of funding for research and development that translate into innovative practices. And rather than focusing exclusively on test scores, educators may wish to decide to nurture the next generation of science students as effective collaborators, teaching them the knowledge and skills necessary to function well in the world of technology, in particular, communications technology.

Quality of Life

One final fact must be considered. If the definition of success in STEM is more about *quality of life for all of the world's students,* then we might agree that we do have a problem. Gaps in STEM achievement and productivity levels between developed and undeveloped countries suggest that, although the picture is changing, we do not enjoy full participation internationally from a wide variety of demographic constituencies in STEM, and this is a loss both to our international community and to young people. STEM skills are among the most highly valued and highly paid skills in the labor force; in developed nations such as the United States, for example, STEM occupations are expected to grow at almost twice the rate of non-STEM occupations through 2018 (American Association of University Women, 2013) and in India, six-fold growth is anticipated (Craig et al., 2011). Because students graduating with STEM majors earn more than non-STEM majors (National Math and Science Initiative, 2013), students with skills in these areas can expect to be highly paid, while students without STEM skills will continue, on average, to earn less than their STEM counterparts. In a number of countries, we can already see the effects of this career income gap made manifest in the growing disparities between the wealthy and poor.

If we agree that this disparity is *the* greatest problem we face today in STEM education, the question becomes what to do about it. Rather than promoting educational practices based on global competition for test scores, nations would do well to think about how to increase STEM productivity for people around the world. Put another way, increasing STEM productivity for one nation does not necessarily take away from another nation, but rather raising the level for everyone becomes a win-win situation, a fact certainly illustrated by the story of Borlaug and his wheat.

Specific steps might include the following:

1. Research the collaborative practices of nations who are top STEM producers, and seek to scaffold the development of these practices in other nations;
2. Work to establish and fund a collaborative university system in less advantaged nations;
3. Work to reduce geopolitical barriers that restrict the flow of information and innovative practices;
4. Work to develop education systems that elevate children out of poverty in less advantaged nations;
5. Teach students to think of themselves as collaborators in a global arena of STEM innovation; and,
6. Provide students with the research and technology skills necessary for them to develop as first-rate scientists and mathematicians into the 21st century and beyond.

Julia Gillard, the first female Prime Minister of Australia, once stated, “My guiding principle is that prosperity can be shared. We can create wealth together. The global economy is not a zero-sum game” (Gillard, 2011). The same argument may be applied to the educational practices that ultimately produce leaders and innovators of global economies. Education need not be a zero-sum game, and during the coming decades, policymakers must come to terms with the stark reality that for their citizens to prosper, they must have such concern for all of the world’s children.

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