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A MEASURE OF THE CREATIVITY OF A NATION IS HOW WELL IT WORKS WITH THOSE BEYOND ITS BORDERS

By John Sexton

WHEN MIKHAIL GORBACHEV FREED ANDREI SAKHAROV TO TRAVEL TO THE U.S., ONE OF the Russian nuclear physicist's first stops was the New York Academy of Sciences. Members of the academy's Board of Governors at that time, in 1988, had been leaders in mobilizing the scientific community to fight for Sakharov's freedom, and Sakharov wanted to extend his thanks for all their efforts.

The story shows how much the world has changed—particularly the scientific world—in the past quarter of a century. At the time of Sakharov's release, only a handful of countries pursued serious scientific research, and still fewer permitted scientific study independent of state interests. Researchers, to the extent that their work required them to collaborate with colleagues beyond national borders, had to scale high boundaries to do so. Today things are quite different.

Globalization (which I sometimes call "planetization" to signal a phenomenon more comprehensive than "globalization" denotes for some) is a defining characteristic of this era in human history. It is not new. In 2004 historian John Coatsworth described globalization as "what happens when the movement of people, goods, or ideas among countries and regions accelerates," and that process has been carrying on in one form or another since modern humans first ventured out of Africa. Something different is happening now, however: the world is miniaturizing. It is no longer possible to keep out the economic, political, cultural or intellectual effects of actions taken in distant lands. Global society operates as a network of creativity and innovation, with a set of "idea capitals" forming the principal nodes of this network. If in the Italian Renaissance, the talent class moved among Milan, Venice, Florence and Rome, today our most creative and innovative citizens move easily among Silicon Valley, Shanghai, London and New York City.

From Aristotle to Stephen Hawking, scientists always have sought to operate beyond sovereignty; indeed, science inherently resists the confinement of boundaries. Copernicus's theories of the solar system led to Galileo's astronomical discoveries, which paved the way for Newton's theory of universal gravitation. Remember, however, that these intimately related breakthroughs occurred over a span of centuries. For most of history the development of scientific understanding was steady but slow, a function of the physical distance between scientists, restricted educational opportunity, lack of resources and political interference. Today the pace of innovation has accelerated drastically.

Indicators of research activity bear witness to an explosion of scientific capacity and a strong trend toward international collaboration. Consider these statistics: in 1996 about 25 percent of scientific articles were written by authors from two or more countries; today the number is more than 35 percent. The share of publications produced by American scientists in collaboration with scientists from other countries increased from 16 percent in 2006 to

TOGETHERNESS: **This circular graph shows collaboration among the 25 nations with the largest science output, as measured in scientific papers that appeared in 2011 in a select group of journals. Not included are collaborations that took place inside each country.**

RLD'S SCIENCE

SOURCES: DIGITAL SCIENCE; MARTIN SZOMSZOR *Digital Science (preliminary data)*

Graphics by Sven Laqua and Arno Ghelfi

30 percent in 2008. In 2008 Chinese scientists were publishing almost six times as many scholarly articles as they did in 1996; today about 10 percent of the world's articles come out of China. In 1989 South Korea did not rank in the top 10 countries filing patent registrations at the U.S. Patent and Trademark Office. Now it ranks third. Since 1995 Turkey has increased its R&D spending by nearly six times and the number of researchers by 43 percent. The list goes on, and all the numbers lead back to the simple fact that there has been a seismic change in the scope and reach of scientific research across national boundaries and within countries not previously represented in major science.

Although the life of the scientist may not be consciously global, the enterprise of science is permeated by globalization in several distinct forms. The base of it—and a good part of the substance of it—is so eminently simple that it could go unnoticed: the speed and ease with which we now communicate have so accelerated the flow of ideas that the scientific enterprise is more interconnected than ever before. And while this greater connectivity has not altered the basic quest—the pursuit of knowledge and the advancement of humankind—the increased globalization of scientific research has created a more open intellectual ecosystem that draws more smart people into the conversation.

For instance, one great recent advance in the fight against malaria is a drug called artemisinin. Just last September the Lasker-DeBakey Clinical Medical Research Award was given to one of the Chinese scientists who led the development of this drug. Artemisinin, however, was actually discovered in China around 40 years ago at the personal request of Chairman Mao Tse-tung, who was seeking to help North Vietnam in its war with the U.S. The isolation of China and its scientists delayed the worldwide awareness of this crucial discovery by seven years—and delayed its availability many years beyond that. And in the 1940s German-American biophysicist Max Delbruck and Italian microbiologist Salvador Luria collaborated on their famous experiment showing that bacterial resistance to viruses is genetically inherited. This was profound work, and they communicated through the most reliable, effective collaborative tool of their day: the post office.

Today, through the Internet and social media, we understand community in a different way; we are more accustomed to coming into intellectual contact with strangers, we are able to expand the pool of talent in new and more successful ways, and we have much deeper relationships with our collaborators. The scientific descendants of these stories most likely use Skype, Facebook or shared networks—or a combination of all three. The volume of data is far more rapid; more colleagues—even nonscientists—are part of the conversation; and the volume of data able to be collected, reviewed and processed is comparatively massive. These differences redefine the concept of collaboration and colleagueship. New York University scientists in mathematics and neuroscience at the New York campus work nearly as closely with their colleagues at our campuses in Shanghai and Abu Dhabi as they do with their colleagues down the corridor, and they share results from the most advanced equipment across campuses.

As a result of interconnectedness, location matters less than ever before. A study of how people process language differently is necessarily made more robust by being conducted in multiple locations. Researchers based in New York City can pursue a study that requires a highly sensitive device for measuring magnetic fields of the brain—despite the potentially disruptive effect of the subway system—by locating the device in another country. No matter what the specific project, scientists in multiple locations around the world can overcome the restraints of the workday. Researchers are extraordinarily hard-working, often visiting their laboratories at night or forgoing vacations while an experiment is being conducted. By operating labs in different time zones, the constraints of time can be overcome, work can continue around the clock and results can be produced more quickly. Increasingly, teams of scientists are using the world's time zones to make their work easier.

The ability to communicate faster regardless of distance has profoundly altered the research agenda. Topics have surfaced that heretofore had not existed or had not been examined. This category includes climate change, food security and humanitarian issues such as water engineering and tropical illnesses. On a sovereign national research agenda, these areas might receive second- or third-tier attention; however, they are top priorities on a global research agenda. Thus, it is not simply that the speed and ease of rapid communication have made the creation of international research teams easier; it also is that the creation of those teams has shaped the questions asked, thus bringing humankind's interconnected challenges to the foreground of scientific attention.

John Sexton was named the 15th president of New York University in 2001. He was chair of the Board of Governors at the New York Academy of Sciences from 2007 to 2011 and is now chair emeritus.

To pursue many of these research projects in the most expeditious way, there is no substitute for true global study. Ocean sea levels and the pressing challenges of managing cities in an increasingly urban world cannot meaningfully be studied except on the enormous scale that globalization allows. Such projects demand that data be collected from around the world, and they marshal brainpower and resources in a way that would have been unimaginable a mere quarter of a century ago. Such undertakings have the complexity of a great symphonic crescendo. Were it not for the tremendous capacity now in place—the sometimes unnoticed change in the way of doing things, the additional actors who can be brought in, the ability to break through space and time—we could not have this kind of dense research. It is like creating one observer's eyes out of many.

In the pursuit of all these research projects, with the enlargement of more and more talent from around the globe and the easy flow of information to support collaboration, the world's scientific community has become less dependent on the U.S. and the West. Many countries now see investment in science and technology as the way to build their economy; the result is larger R&D budgets, which, in turn, are producing more robust academic collaborations with international colleagues. For exam-

SOURCE: NYU PHOTO BUREAU/MADERE

ple, the number of science and engineering Ph.D.'s awarded at Asian universities, especially in China, is increasing, whereas the number awarded in the U.S. is decreasing. Fifteen years ago the U.S. published more than 10 times as many scientific papers as China, and Chinese scientists were almost invisible in scientific journals. Two years ago China ranked second in the world in published papers; it could overtake the U.S. by next year. During the past decade China, India and Brazil more than doubled their expenditures on research and development—increasing their contributions to world R&D spending from 17 to 24 percent. A 2010 report by the U.S. patent office showed that American dominance of patents issued by the U.S. ended in 2008, when patents of foreign origin surpassed those originating in the U.S. And a Thomson Reuters report showed that China surpassed the U.S. and Japan in new patent applications last year.

This intensified activity around the world has certainly been to the good. Globalization, as manifested in international collaboration on "big science" projects, is now taken for granted. The Human Genome Project, the International Space Station, the Large Hadron Collider at CERN near Geneva and ITER (formerly the International Thermonuclear Experimental Reactor) in France are only a few examples. The globalization of science has been a boon for humanity.

We should be cautious, however, about overly congratulating ourselves. Although scientists have become ever more able to reach out to one another and the scientific community has become ever more cohesive, there are considerable risks and challenges. Many stem from a great tension of our time: as the world grows more connected, individuals and institutions have sought out new ways to draw boundaries.

Despite how much more encompassing the conversation about science may be and how many more people we involve, many are still excluded. Throughout the world there are those with little or no access to the telecommunications revolution or the Internet, much less to advanced education or technical knowledge. As long as these conditions continue, we will have too many people of talent absent from important conversations. The real danger is that this trend is self-reinforcing and that the gap in scientific capacity between developed and less developed nations will widen.

MANY COUNTRIES SEE SCIENCE AND TECHNOLOGY AS A WAY TO BUILD THEIR ECONOMY. THE RESULT IS LARGER R&D BUDGETS.

Similarly, we need to guard against losing our ability to hear the voices of those at the margins who challenge orthodoxies—some of our greatest breakthroughs have come from that quarter. Put another way, we need to be mindful of the perils of "groupthink" or "fast-think." Whereas new technologies bring scholars, researchers and even nonscientists together in remarkably efficient and beneficial ways, these media and new virtual communities may reinforce conventional wisdom. With the same goal in mind, we will also need to have clearer understandings about intellectual property. Pervasive suspicion that the fruits of research will not be properly respected in other locations could have a devastating impact on collaboration and the development of new concepts.

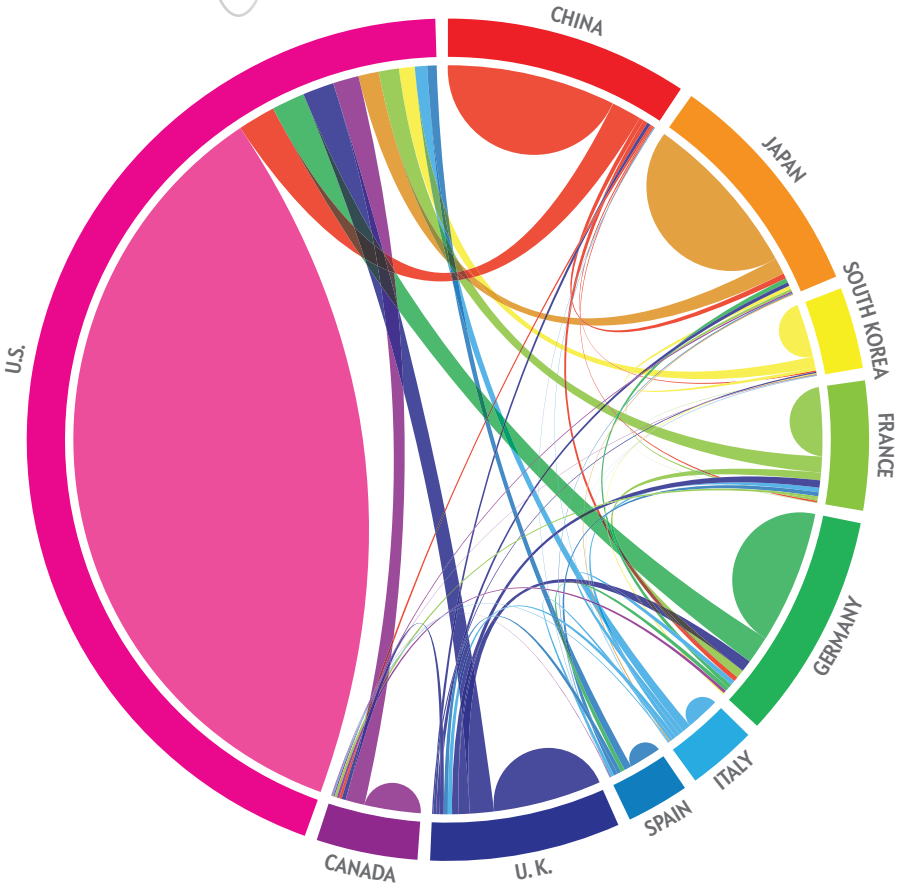
Immigration policies can impede the workings of the new global research. Although communication and collaboration have never been easier, many universities, in particular, find themselves confronting ever more serious immigration-related problems—collaborators unable to obtain visas, graduate students accepted into programs but unable to enter the country because of their nationality. National security is rightly a top priority for the U.S. and other Western countries, but we will need to fine-tune the balance of principles more carefully if we are to participate fully in a world science community.

Even within the community of established research institutions, some troublesome tensions persist or are exacerbated by globalization. And although some of our finest universities are altering their fundamental architecture in response to globalization—Duke University president Richard Brodhead said recently that by the middle of this century the great universities will be "global network universities"—the institutions that have the most experience in operating globally are corporations. The two have increasingly become partners, with corporations funding more and more academic research. This alliance presents challenges that demand the attention of the scientific community.

First, because universities are interested primarily in the advancement of knowledge (in science and other fields), they have been homes to basic research, some of which has led to enormous though unpredictable advances. Because corporations want specific results and products, they are less interested in basic research (the heyday of Bell Labs is behind us). Thus, to the extent research funding is tied to corporate interests, there will be a lamentable diminution in funding for basic research. Second, corporate funding, we have learned, can be tied (by implication) to specific outcomes. For instance, drug companies have manipulated research in ways that have led to questionable science supporting questionable claims of a drug's efficacy.

This is not to say there should be *no* science with corporate funding. Yet a global corporation, itself operating beyond sovereignty, can be powerful, and we must remind ourselves that the master of science is knowledge. And we must strengthen structures and processes designed to protect the advancement of science.

The blossoming of collaborative research is a good thing, not least because it has encouraged more governments—Western and (increasingly) Eastern—to devote major resources to scientific research. The incentives to participate in multinational teams, however, may fade unless we address some basic problems. For instance, can a scientist be funded for the same or related projects by two different sovereign states? If so, can they be any



WITHIN: Plot includes internal collaborations in the 10 nations with the highest science output. U.S. researchers work with one another more than with outsiders.

two or only political allies? Currently, as many universities become eligible for significant scientific funding from sovereigns in the Middle East or Asia, the rules governing grants from the U.S. government (especially the rules in the area of "deemed exports") make many of these multifunded projects difficult if not impossible. Are restrictive policies good for science? Will they, in the long run, tend to isolate American scientists if applied strictly? For that matter, who owns the intellectual property produced by multinational teams, especially ones that are funded by more than one sovereign? Is this simply a matter of a contract between the participating bodies, or do the governments, by virtue of funding part (perhaps an undifferentiable part) of the project, have a claim?

U.S. institutions, in particular, are very conscious of research funding statistics as a benchmark for judging the quality of research. Will only funding that comes from U.S. sources continue to count in those rankings?

As the forces of globalization define the trajectory of scientific inquiry for the century, these overarching issues will determine the role and value of science in our lives. Will scientific research be open to all or an opportunity only for the privileged? Will research focus on worldwide needs or narrow interests? Will the scientific community accept disruptive ideas or rely on conventional wisdom? Will countries remain wedded to outmoded rules or be flexible enough to permit deep collaborations on research?

Access to the worldwide discussion about science has never been greater, making participation and advancement a meritocratic exercise. The constantly changing conversations provide unprecedented opportunities to learn, to question assumptions and to break down the walls between disciplines and fields. Yet our trajectory is never inevitably upward. We must take care to make it so.

There is a reason that the Renaissance resulted in so many of the discoveries that still shape our lives. The city-states were idea capitals that brought together the best minds of the time, thus creating communities of individuals who were constantly questioning one another about existing common assumptions. Ultimately the participants became independent enough to be devoted only to the truth. No less than that should be our ideal now.

Which brings us back to Sakharov. Consider this question: Why were so many of the leading Soviet dissidents scientists? One reason is that science created an opportunity for brilliant individuals to excel, despite an environment of deprivation and bureaucratic state control. Scientists, by necessity, because of the nature of their work, had some contact with the international community. And probably most important, scientific inquiry encourages a level of intellectual rigor that would naturally lead one to challenge a broken, despotic system.

Such is case with Alaa Al Aswany, an acclaimed Egyptian novelist who was one of the chief critics of the deposed Mubarak regime. In between his writing and speaking about Egypt's future, he is a working dentist, with an advanced degree from the University of Illinois. As the *New York Times* recounted in a 2008 profile of him, "His three years studying for a master's degree in dentistry in the United States was the most important period in his life. He admits that he had a caricature vision of America, but his travels and discoveries—of, among other things, a gay church and a black pride organization—convinced him that there was more to the United States than what he calls its 'imperialism' in the Arab World."

Aside from the benefits of all the discoveries resulting from globalized science, the spread of scientific research and training will become part and parcel of the opening up and intermingling of societies around the world. No country will be able to forgo the benefits of science, and as they train young people at universities, they will be creating a class that thinks globally, demands responsive institutions and prospers despite local impediments. These new leaders, in the tradition of Sakharov, will be the vanguard of the next stage of globalization.

SOURCES: DIGITAL SCIENCE: MARTIN SZOMSZOR *Digital Science*