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Challenges and New Requirements for International Mega-Science Collabortions

Stefano Lami

Innovative research in nearly all scientific fields today requires complex facilities and cutting-edge technologies. This reality confers high costs for large-scale, long-term projects. Major collaborative efforts, often international in scope, are thus becoming a common means to reduce costs, share risk, and augment scientific expertise.

Several authors have written about the growing importance of global scientific engagement, usually emphasizing its components of synergy, science diplomacy, and beneficial impacts on economies.1-7 Yet this shift toward international mega-science collaborations is creating challenges and even barriers that cannot be overcome through current agreement structures and other coordination mechanisms. The level of engagement required by such international collaborations, particularly in terms of mobility for scientific personnel and equipment, goes well beyond the traditional solution of drafting simple memoranda of understanding. New kinds of agreements and other mechanisms will be necessary to ease complex customs transactions for the movement of scientific instrumentation; at the same

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time, ministries of foreign affairs must prepare to issue more visas to facilitate this unprecedented global mobility.

Growth and Change in Global Scientific Collaborations

Scientific research and innovation are among the most powerful forces driving economic development and social change. Yet while scientific research facilities become larger, more complex, and require more resources, funding for scientific research is often not increasing in many countries even as the timescale for projects. Faced with these intimidating technical and financial challenges, science can either abandon its exploratory spirit or adapt by fostering greater coordination and collaboration on a global scale.

As far back as 1995, the now-defunct U.S. Office of Technology Assessment warned in a report to Congress that, while federal investments in research and development had been crucial to many of the nation's achievements in basic sciences, budgetary pressures had made it difficult to sustain existing government R&D efforts and to initiate new ventures.8 While the United States already had several decades of experience with international scientific collaborations, these were mostly small-scale projects and its experience in the joint operation of large-scale endeavors was far more limited. The report, therefore, recommended that Congress consider international collaboration in any large, complex scientific undertaking with the aim of reducing costs, sharing risks, and enhancing scientific capabilities. And it addressed issues "relevant to congressional authorization, appropriation, and oversight of ongoing and upcoming large science projects. These include the International Space Station (ISS) and the International Thermonuclear Experimental Reactor (ITER), as well as U.S. participation in the Large Hadron Collider (LHC) project at the European Laboratory for Particle Physics (CERN).9

More recently, but along the same lines, came the opening of the U.S. National Aeronautics and Space Administration (NASA) to international cooperation using analog missions to answer space research questions. This path culminated in NASA cooperation with private entities on commercial spaceflights. By using Space Act Agreements, NASA and its partners would settle on a series of mutually beneficial activities—including expansion of the human presence into the solar system and to the surface of Mars—toward advancing NASA's strategic goals in exploration, science, innovation, and international collaboration.10 By design, the partnerships involved no exchange of funds, with each party bearing the costs of its participation.

This is but one example of how global planning in science has advanced greatly since the OTA's 1995 report, especially with U.S., European, and Japanese strategies achieving broad alignment and the processes that drive them becoming ever more closely linked. Clearly, to secure a long-term future for science innovation, the world science community needs to continue to promote strong worldwide collaborations, develop synergies, and bring new and emerging players, such as those in Asia, into the fold.

As a beneficial collateral effect, these collaborations have revealed the great importance of science for diplomacy. International laboratories such as CERN, the European Organization for Nuclear Research, in Switzerland, and the Synchrotron-light for Experimental Science and Applications in the Middle East (SESAME), in Jordan, are now well-known examples of peaceful international collaboration based on transparency, openness, and inclusion.

The invention of the World Wide Web at CERN is emblematic of the spirit behind advances in basic science, which in turn enable open innovation and education and connect the global community through shared values. Places like CERN are vitally important agents in the innovation chain, contributing to knowledge that not only enriches humanity but also provides ideas that become technologies of the future. Furthermore, they train the next generation of scientists. All this is possible because governments support science, technology, engineering, and mathematics (STEM) education and basic research.

In October 2014, I participated in CERN's sixtieth-anniversary celebration at the United Nations headquarters in New York, where CERN was presented as a model of science for peace and diplomacy, a place where scientists from around the world are working together regardless of race or religion.11 The ambitious UN Sustainable Development Goals,12 which came into force January 1, 2016, and will last fifteen years as part of the body's 2030 Agenda for Sustainable Development, have an encouraging focus on science and technology. They testify to a deeper understanding of science as a driver of progress that benefits all peoples and helps overcome today's most pressing development challenges.

The SESAME project, for its part, represents an audacious effort to use science for diplomacy in the heart of the Middle East. It is a unique joint venture that brings together scientists from Bahrain, Cyprus, Egypt, Iran, Israel, Jordan, Pakistan, the Palestinian Authority, and Turkey. The facility will provide an intense source of light, including infrared and X-ray wavelengths, allowing researchers from the region to investigate the properties of advanced materials, biological processes, and cultural artifacts. SESAME Council members share a vision: to unite scientists from many Arab and Muslim-majority nations, along with Israel, to work together toward common scientific goals.

Overall today, global governance is more complex than ever, with overlapping challenges and a greater number of interlocutors. Public opinion is likewise being formed in new ways, driven by technological advances and political change. Global economic shifts, with emerging countries gaining influence and clout, are shaping policy priorities, including in science. Support for fundamental science must therefore be constantly nurtured, and partnerships are more necessary than ever.

International mega-science collaboration occupies a highly complex and fast-moving policy space. All large laboratories and research infrastructures need to both react to and act within this evolving context. Given the linked futures of international laboratories, their communities are moving ever closer together. The pressing challenge, according to one UN official, is to advance in a globally coordinated manner that enables the scientific community to carry out "as many exciting and complementary projects as possible, while ensuring long-term support for fundamental science as the competition for resources becomes ever fiercer on all levels."13

U.S. Participation in Mega-Science Projects

There are many examples of U.S. participation in very large international projects. In addition to the aforementioned ISS, LHC, and ITER, such involvement includes the Laser Interferometer Gravitational-Wave Observatory (LIGO) and the Global Network of Gravitational Wave Detectors; the Human Genome Project; the Global BRAIN Initiative; and the Thirty Meter Telescope.

The recent discovery of gravitational waves by the LIGO Scientific Collaboration and the Virgo Collaboration,14 thanks to the two LIGO detectors—funded by the U.S. National Science Foundation (NSF)—has drawn heightened attention to the need to expand over the next three decades the global network of gravitational wave interferometers, with the goal of maximizing the scientific potential of gravitational wave studies. Among the first questions that must be answered about each gravitational wave observed is where it originates. A global network of detectors can answer this question by comparing the signals at widely separated detectors. This will enable gravitational wave sources to be studied using the tools of multi-messenger astronomy, such as optical telescopes, radio telescopes, or X-ray detectors. In addition to the two U.S. LIGO detectors are the advanced Virgo in Pisa, Italy (a French-Italian collaboration), and GEO600 in Hannover, Germany. Separately, the Kamioka Gravitational Wave Detector (KAGRA), an underground cryogenic detector in Japan, is almost complete. LIGO-India will join the international network in the next few years. Thus, LIGO exemplifies how international collaborations are now moving from the regional to the international level, characterized by joint data-taking and a large-scale exchange of researchers.

The field of neuroscience, too, is entering a collaborative era in which powerful new technologies, generated by large scientific projects in many countries, will have a dramatic impact on science, medicine, and society. The newborn Global BRAIN Initiative is designed to coordinate several such initiatives launched over the past five years in many different countries, ensuring broad distribution of novel technologies and open accessibility to the data generated, thereby multiplying their value. At the September 2016 meeting in New York that launched this global initiative, attended by neuroscientists and neuroscience administrators from around the world, the aforementioned Global Network of Gravitational Wave Detectors was discussed as a model for international collaboration that neuroscientists might emulate.15

The international collaboration forming around the U.S. neutrino physics program will likewise bring a new dimension to global collaboration in particle physics. After the respective closures of the PEP-II and Tevatron accelerators at the SLAC National Laboratory Accelerator, at Stanford, and the Fermi National Accelerator Laboratory (Fermilab), in Illinois—and given the attraction of many U.S. physicists to the LHC at CERN—a May 2014 report known as the P516 defined a decade-long strategy for retaining high-quality research in the United States while optimizing investments. Such a priority level was given to neutrino physics and to relaunching Fermilab. The Fermilab director, Nigel Lockyer, in his testimony to the U.S. Senate on the P5 report, emphasized the essential importance of international partnerships.

Mobility for Scientific Personnel and Instrumentation

The necessity of optimizing resources, combined with the high complexity of research technologies and facilities, has accelerated the globalization of Big Science projects. Yet this swift growth and transformation have not been accompanied by parallel advances in governance mechanisms capable of easing related challenges.

Little discussion appears in the peer-reviewed literature about strategies for improving scientific personnel - and instrument - exchange mechanisms. Since the September 11, 2001, terrorist attacks, the governance of international transport of scientific instruments and other supplies has focused mainly on scrutiny of shipments of potentially "dual-use" equipment. Means of handling this issue from a scientific-collaboration perspective are still lacking.17

The Organisation for Economic Co-operation and Development (OECD), an international body with more than thirty member countries including the United States, periodically organizes the Global Science Forum (GSF), a venue for consultations among senior science policy officials on matters relating to scientific research. The GSF activities produce recommendations for actions by governments, international organizations, and the scientific community.

Recognizing the need for greater international and interdisciplinary cooperation on S&T issues, the GSF's "Strategic Directions, 2015–2019"18 report recommended facilitating the development of new collaborative mechanisms and policies that lower barriers to international cooperation. However, this report does not address the mobility of scientific personnel and instruments, leaving gaps in the proposed governance.

One particular bright spot for bilateral S&T cooperation, stretching from the end of the Second World War, has been that between Italy and the United States. This relationship was defined clearly, and reinforced, through a 1988 U.S.-Italy intergovernmental agreement.19 In physics in particular, the exchange of know-how between national laboratories involved in joint projects has over the years created lasting ties, an endeavor in which the scientific office at the Italian embassy in Washington, D.C., has played a fundamental role.

Working at this embassy, I collaborated with the Italian Ministry of Education, University, and Research and the U.S. Department of Energy to prepare a framework agreement for cooperation in physics on several fronts: from the detection of neutrinos and dark matter at the Italian Gran Sasso National Laboratories to the study of neutrinos at Fermilab and of atomic nuclei at the Jefferson Lab20 in Virginia; from the space program for the study of cosmic rays and antimatter with the Fermi and Alpha-Magnetic Spectrometer (AMS) space detectors to the detection of gravitational waves with the LIGO and Virgo interferometers and the study of high-energy cosmic rays with the Pierre Auger Observatory in the Argentinian Pampas.

The agreement, which was signed in 2015, attempts to meet, in very broad terms, the needs of future large international partnerships, especially concerning the exchange of personnel and scientific material. Among a variety of provisions designed to facilitate this outcome was a statement that any exchanged equipment used to conduct joint activities should be considered scientific rather than commercial in character and, therefore, eligible for duty-free entry.

More work must be done by the relevant ministries, however, to surmount the inevitable national and international legal barriers to such exchanges. For instance, mega-science international projects often involve the delivery of a huge amount of instrumentation, requiring the easing of complex customs transactions. As an example, the aforementioned U.S.-Italy agreement required a special annex regarding the transfer of the ICARUS particle detector from the Italian Gran Sasso National Laboratories to Fermilab, a shipment to be completed in 2017. This 760-ton, sixty-five-foot-long detector contains, in addition to its infrastructure and instruments, 600 tons of liquid argon, and it will become an integral part of neutrino research at the U.S. national laboratory, the first step forward in Fermilab's plan to host a truly international neutrino facility.

Along these same lines, a new agreement, signed in 2015 in a White House ceremony by the U.S. Department of Energy, NSF, and CERN, cleared the path for renewed collaboration in particle physics, promising to yield insights into fundamental particles and the nature of matter and our universe.21 And in May 2017, three addenda to that agreement established the specific contributions for next-generation experiments and scientific infrastructure located both at CERN and in the United States.22 For the first time in its history, CERN will contribute to a project outside Europe, the U.S.-based neutrino program hosted by Fermilab.

For various reasons, an entirely new kind of agreement is needed for these and future huge scientific projects and facilities.

A Visa for Scientists in the European Union

If international science collaboration has grown at an astonishing rate, the support needed for the exchange of researchers has not kept pace. Foreign affairs ministries will thus have the task of simplifying entry visas for researchers, given that researcher mobility is essential to international S&T cooperation.

The notion of a "scientific visa" to legislatively allow researchers' mobility has been under discussion for decades but never implemented with full effectiveness.23 Through Horizon 2020, the Framework Programme for Research and Innovation, the European Union has tried to offer multiple opportunities for the transit of researchers between the continent and the rest of the world. The EU has thus recommended, since 2008, that member states incorporate a "scientific visa package"24 into their national legislations to ensure smooth administrative procedures for visa approval and to facilitate entry into Europe for researchers from third countries.25 Such implementation by respective countries has slowly converged, with slightly different shades, toward a more uniform system, but it still requires several improvements.

Some European scientific laboratories have gone one step farther. For instance, CERN, whose facilities are located in Swiss and French territory, is qualified as an international organization and has always helped researchers acquire a residence permit in either country, assuming they are working more than 50 percent of their time at CERN with a contract longer than three months. In fact, the Swiss Federal Department of Foreign Affairs issues a carte de legitimation ("Swiss card") to CERN researchers and their family members providing immunity from jurisdiction in Switzerland in exercising their functions. And it entitles the holder to live in Switzerland and to travel within the Schengen Area without a visa. Likewise, the French Ministry of Foreign Affairs grants CERN personnel and their family members a French card (titre de séjour spécial or attestation de fonctions) functioning just like the Swiss equivalent.

More generally and more recently, non-EU holders of a "scientist/researcher" long-stay visa (e.g., scientists, researchers, or university teachers) are now allowed to reside in France for up to twelve months, subject to the validity of their visa. Given a valid visa, they will no longer be required to obtain a residence permit from the French local authorities. Of course, nationals coming from the EU, Schengen states, and European Economic Area member countries benefit from the visa-exempt status, too. They can move in EU countries without a visa by producing a valid passport or national identity card.

Non-EU citizens wishing to carry out research in EU countries do need to meet certain obligations. Namely, they must have concluded a hosting agreement with a recognized private or public research institution, obtain a scientific research visa before arrival, and then apply for a residence permit to perform scientific research. The bureaucratic time line may be long, and each particular country may require an annual renewal. A 2014 Italian law was created to simplify the procedure with respect to income resources and a self-declaration of the researcher's educational qualification. The Italian 2017 budget law provides benefits and a special visa to foreign investors willing to open a start-up in Italy, but not much beyond this has been done for researchers. However, the same budget law establishes that, in the event foreign researchers or university teachers decide to establish residency in Italy, only 10 percent of their Italian wages will be taxed in the first four years.

The U.S. Visa Crisis

In recent decades, the United States has been an attractive choice for many of the brightest minds around the world, given its reputation for allowing unencumbered scientific discovery and exchange.26 In 2014, about half of biomedical scientists in the United States were foreign-born and a third were noncitizens.28 Between 1995 and 2005, a quarter of U.S. high-tech start-ups had an immigrant founder who first came to America as an international student.29 International students contributed nearly $33 billion to the U.S. economy during the 2015–2016 academic year, supporting more than 400,000 U.S. jobs.30 Meanwhile, thousands of foreign scientists travel to the United States every year for specific projects, contributing substantially to mega-science collaborations where U.S. universities and agencies are involved.

Thus, whereas the Cold War period (1945–1990) was characterized globally by "isolation and control" of information and innovation for national security and commercialization purposes, the twenty-first-century paradigm emphasizes "partnerships and engagement" to most effectively accelerate innovation, discovery in science, and creation of technologies. However, as pointed out in a 2012 study by the National Academy of Sciences, many U.S. policies, such as those on export controls, or travel, visa, and employment restrictions for foreign visitors, were implemented during the earlier period, making them not necessarily adaptive in a rapidly changing world.31

The situation has worsened since the attacks of September 11, 2001. In responding to national and global security concerns, the United States has put in place visa and immigration processes that have made it more difficult for some scientists and engineers to study, conduct research, work, or even attend meetings and conferences in this country. Visa restrictions that prevent foreign researchers from returning to the United States for various intervals inevitably impose limitations on cooperation that could benefit both the United States and the researchers' home countries. The short- and long-term repercussions can be serious when the brightest researchers turn away from opportunities in the United States to accept those offered in other countries. The United States is today in a worldwide competition for the best scientific talent, and without a change in its visa system that lowers barriers to entry, many of the top students and scientists in other countries will simply choose to go elsewhere. Further, U.S. government researchers face their own travel restrictions, limiting direct interaction with research developments around the world.32

Whereas many elements of the U.S. visa system involve obsolete categories that do not apply easily to today's researchers, others derive from equally outdated immigration policies aimed at determining the true intent of foreigners seeking to enter the United States. In still other cases, the security or terrorism concerns that prompted regulations have been remedied—yet the rules remain.33 A notional crackdown on H-1B visas, the nonimmigrant work permit for foreigners in specialty occupations such as scientists, engineers, and physicians, would seriously threaten cutting-edge U.S. scientific research, including medicine and biotech industries.

Strategic Goals for International Cooperation in Science and Technology

Through international cooperation, partners can achieve the highly demanding and costly management of large-scale, long-term science projects. Science policy makers, in seeking effective future partnerships, could identify models and "best practices" in any of several international research institutions or distributed research infrastructures. Yet building from such models will not be enough. Given the fast evolution toward mega-science projects, current agreements and mechanisms must be adapted to keep up, even as national and international legal barriers often stand in the way of needed new agreements. Overcoming such barriers to mobility for both scientific personnel and equipment (by simplifying present regulations) would probably necessitate legislative action for some proposals and administrative steps for others. All can and should be achieved without compromising security.

International scientific bodies such as the OECD Global Science Forum and the UN Scientific Advisory Board should persist in recommending policies that lower the barriers to international cooperation and knowledge sharing, and set new strategic and programmatic goals. For instance, to protect their education and training, countries could ease acquisition of residency for students who graduate from their universities. In Australia, foreign students can acquire a visa to work for up to eighteen months after graduation, and for certain high-need occupations, this can be extended for up to four years.34 Following graduation, foreign students in Canada can work for a period equal to the span of their study in Canada, up to a maximum of three years. Skilled Canadian work experience gained through this program helps graduates qualify for permanent residence in the country.35

In the United States, as already noted, visa policies make it much more difficult for U.S. and foreign scientists to share ideas and collaborate. The complex regulations of the J-1 exchange visitor visa, the most widely used type for visitors coming temporarily to conduct research or teach at U.S. institutions, should be simplified. Also, the F-1 visa (nonimmigrant student) needs a more flexible policy that permits qualified international students to remain in the United States without allowing the student visa to become an easy way to subvert regulations on permanent immigration.36 The Visas Mantis clearance process, which was implemented in 1998 and applies to all categories of nonimmigrant visas, is currently causing delays in visa processing. This scenario is triggered when a consular officer believes an applicant might be ineligible for a visa for security-related reasons, and in the last several years it has created a large workload for the State Department. A possible solution could be to use scientifically trained staff within the State Department, such as AAAS Fellows or other fellows sponsored by the National Academies, as advisors to consular officers in the nonimmigrant visa process for scholars and researchers. They, and other Foreign Service Officers with technical backgrounds, would be especially useful in countries that send large numbers of STEM students and visitors to the United States, such as China, India, and South Korea.37

Science and technology are moving at a rapid pace that society is struggling to match. International scientific cooperation is the new endeavor, and we should work to promote it rather than place obstacles in its way. A widespread scientific visa should not be an unreachable illusion. Scientific agencies and organizations can support such an undertaking, and we as individuals can bring these problems to the attention of the representatives of our governments. SD

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