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How Collaborating in International Science Helps America

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International collaborations embed American scientists and students in vibrant, globally collaborative networks that strengthen the U.S. science, technology, and innovation (STI) enterprise, while benefiting both America and the world. Because such benefits have not been systematically explored in the United States, we present a framework for organizing and enumerating them, with national-level examples provided to illustrate scientific, economic, health, national security,

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educational, societal, and diplomacy and development advantages that can result from international STI collaborations. Our objectives in presenting this organizing structure are threefold. First, the framework can help those in government, academic, and private sectors who make decisions with national impact better understand how and what kinds of positive outcomes can result from international STI cooperation. Second, given the distributed and decentralized nature of the U.S. STI community, the framework can serve as a starting point for subnational decision makers to identify benefits of STI internationalization at their operational scales. Third, this organizing structure and its examples can serve as a call to action for scientists to more clearly articulate to decision makers and the public how working in areas of mutual scientific interest with international colleagues can advance U.S. national, regional, local, or institutional interests.

As a group of individuals who have worked across national and global science landscapes for many decades, we were motivated to develop a framework for better understanding and communicating the benefits of international science,[1] technology, and innovation collaboration to the United States. The global STI system has seen dramatic change in the last several decades. For example, it is now marked by worldwide growth in investment that is significantly reducing U.S. global scientific market share, e.g., in expenditures, globally mobile students, publications, patents, and technology revenue."[2,3] The construction of advanced STI infrastructure is now more often built outside the United States by other nations or consortia. And the geography of scientific knowledge creation and use has shown new dynamics within and across many world regions.[2,4,5] These changes have kindled a dialogue in the United States about how the nation, facing both a more worldwide distribution of STI excellence and domestic budget constraints, can best adapt to the twenty-first-century environment of international partnerships and globally distributed knowledge networks.[6,7,8,9,10] Missing thus far from this dialogue has been a comprehensive and deliberate exploration of how international STI collaboration provides benefits to America at many levels.

We undertake such an effort by presenting an organizing structure or framework for such benefits that we hope achieves three objectives. First, given the complexity of the U.S. STI enterprise, this framework can help decision makers (including government officials at all levels, as well as academic and private sector leaders) better understand how and what kinds of positive national impacts can result from international STI cooperation. We do this by providing examples within our framework of who can benefit, in what ways, from which types of activities undertaken by different sets of U.S. and foreign partners working in various policy sectors. Second, the framework can serve as a starting point for subnational decision makers to identify benefits of STI internationalization at their operational scales. Third, this organizing structure and its examples can serve as a call to action for scientists to more clearly articulate the benefits of their international collaborations to decision makers and the public.

The Underappreciated Value of International Scientific Collaborations at Home

The United States has been slow among developed and emerging economy countries to recognize how increased international collaboration can advance domestic science excellence.[11,12,13] This is likely due to America's historic STI dominance, relative geographic isolation, and critically, to a complex STI community that is large, diverse, and decentralized. Much U.S. scientific activity is of a bottom-up, merit-based nature, driven by scientists working in domestic or international teams to address specific scientific challenges, rather than being dictated by centralized, top-down mandates.

The nation distributes federal support for basic scientific research from a number of agencies and across many universities and research institutions. U.S. higher education is a private or state, not a federal, responsibility, so academic STI internationalization is characterized by strong competition among states and institutions, few national policy levers, and little coordination among and within institutions.[14] Likewise, the various U.S. government science agencies operate in a relatively decentralized manner, undertaking international activities to meet their different missions with little policy direction, and with limited central and strategic coordination.[15,16] Congress and State Houses respond to local constituencies, yielding few broad national advocates for international STI collaboration. Finally, because STI results and impacts, especially those that occur in overseas collaborations, are primarily communicated across networks of scientific professionals, little feedback on international STI outcomes is available in forms that are accessible to decision makers or the general public.

Given these historical and structural considerations, we chose to focus on benefits derived from federal government and university involvement in international STI activities that advance national objectives such as national security, economic vitality, and diplomacy. We focus on Americans going abroad for STI collaboration because this has received less attention than the impact of foreign STI researchers and students working in America. We recognize that the mutual benefit realized by the collaborating foreign partner(s) is essential to this STI cooperation, but we do not address that here.

Crafting a Framework to Capture Benefits of International STI Collaborations

Our framework organizes benefits into seven sectors (i.e., scientific, economic, health, diplomacy and development, national security, educational, and societal) with distinct (or overlapping) policy drivers and potential policy outcomes (e.g., leading, accelerating, building, safeguarding, sustaining)[18] Because our primary objective is to inform those whose decisions have major impacts at a national level, most of the examples in Table 1 focus on how international collaboration in national programs can help the United States. The examples illustrate an

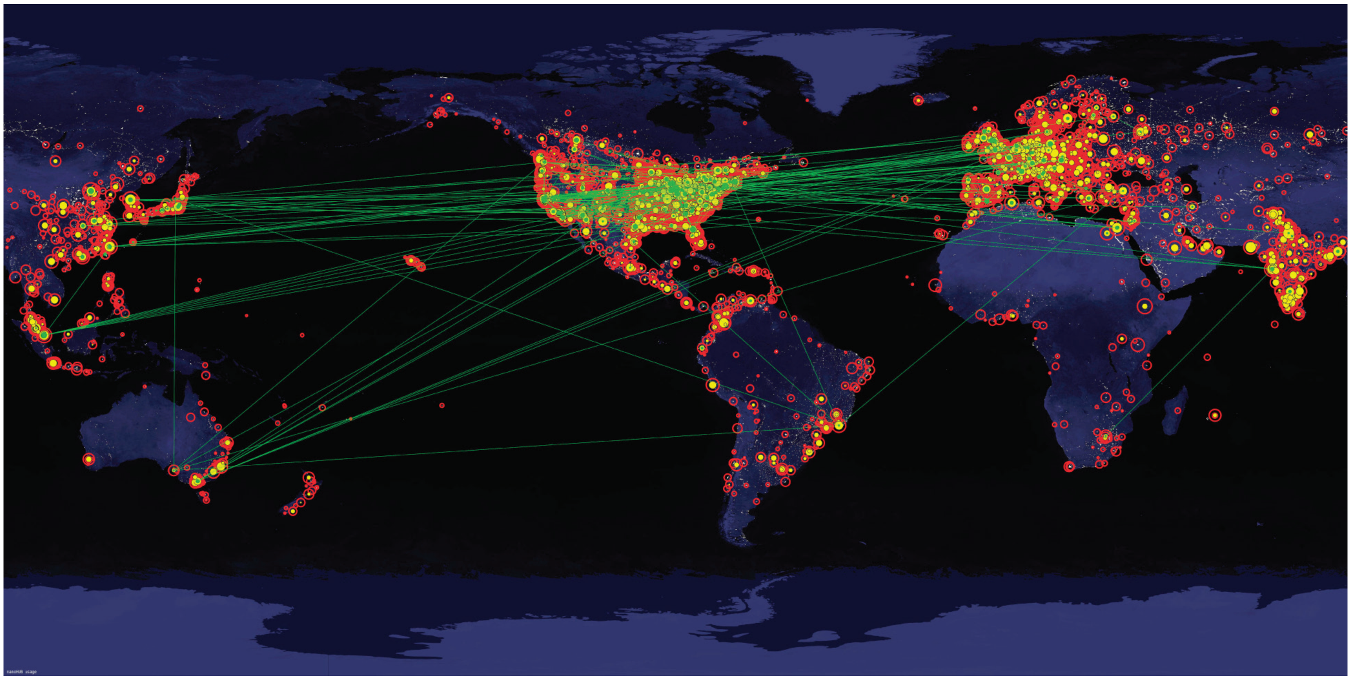

Figure 1: *Illustration represents annual number of Network for Computational Nanotechnology users. Greater activity is indicated by larger dots with a more yellow than red color. Photo Credit: Network for Computational Nanotechnology, Purdue University; https://nanohub.org/*

overarching benefit of international collaboration, i.e., it yields outcomes that no one nation could achieve alone. For example, international groups can leverage more resources (e.g., funding, expertise, facilities) to accomplish something faster and can combine diverse contributions (e.g., unique expertise, data, phenomena, facilities) to allow specialization and reduce duplication. Such collaborations can also increase collective participation (e.g., comprehensive global or regional monitoring) to yield more rigorous scientific synthesis and shared responsibility for future action. The examples also document how international STI collaboration can strengthen relationships (e.g., with improved networks and collaboration tools, and increased trust, generosity, and cultural understanding) with mutual scientific and diplomatic benefit to all participants. Finally, the examples sampled in Table 1 demonstrate the wide potential scope and complexity of projects, with various types and numbers of international partners, and diverse types of scientific activities undertaken to yield the set of benefits described.

Many of the activities cited in Table 1 are part of a rich fabric of cooperation that produces benefits across multiple sectors. For example, in the category of societal benefits, when U.S. engineers work with their Japanese counterparts on building safety, they contribute to society's resilience to earthquakes by co-designing and sharing data from experiments in Japan on the world's largest "shake table," subjecting large, sensor-laden reinforced concrete buildings to different types and severity of shaking. A recent U.S.-Japan workshop on risk communication yielded additional societal benefit by providing cross-cultural insights into how to increase effective engagement with the public in natural disaster preparedness and response. Universities in the earthquake-prone nations of Japan, New Zealand, Chile, and the United States are linked in a virtual network that generates scientific benefit by sharing data on earthquake impacts on various kinds of buildings, as well as educational benefits to the participating countries by engaging their future engineers in jointly taught classes and international collaborative frameworks. The graphic of nanoHUB users around the world (1, see also Table 1), illustrates another international collaboration that yields multiple types of benefits. In addition to building a community of shared practice around nanotechnology safeguards that spreads the costs of nanotechnology safety across many countries, nanoHUB distributes nanoscience educational materials from around the world and provides worldwide access to computing and simulation tools in nanoscience. The United States benefits from the resultant global knowledge networks and thriving national and international educational and research collaborations in the pre-competitive areas of nanoscience.

We highlight direct positive impacts of STI collaboration for the wellbeing of Americans and emphasize how U.S. leadership in solving global STI challenges can benefit the world. We hope that our focus on the benefits of leveraging increased worldwide STI excellence provides a positive counterbalance to concerns that such global STI growth is primarily a threat that diminishes U.S. advantage.[19] We recognize that global technology markets are fiercely competitive, that there are ongoing threats to American intellectual property, and that the nation needs to safeguard its technology for national security. But these concerns need not interfere with global engagement—many safeguards exist and are continually reinforced. There are numerous examples of international cooperation in pre-competitive research that are successfully integrated into domestic technology programs and subsequently implemented by U.S. business and government agencies. Many American industries have adopted a strategy of open collaboration to stay competitive.[20] Given the breakneck speed at which STI developments emerge and expand across the globe, we endorse the view that "American security and prosperity now depend on maintaining active engagement with worldwide developments in science and technology, and with the global economy."[21] Embedding American scientists and engineers in robust, global STI networks can add value by placing local knowledge in global contexts and by bringing global knowledge back for local use.[22]

Our second objective in presenting the information in Table 1 is that it serves as a starting point to help various subnational decision makers and stakeholder groups better understand the potential benefits of international STI collaboration at the levels at which they operate. Each state has a unique set of universities, industries, populations, and political and economic drivers. To paraphrase the late Supreme Court Justice Louis Brandeis, the states can be America's "laboratories of STI globalization," where state policies allow experimentation and local fine-tuning, delivering benefits from each state's distinctive comparative advantages.

We know that the map of innovation has been "spiky," with a few key regions (e.g., San Francisco and Boston) dominating.[23] Looking ahead, America's challenge is to sustain existing hubs and incubate new ones that can achieve site-specific local-to-global STI integration; this is especially pressing as more emerging economies devise their own recipes for innovation's "special sauce," that is, mega-cities that co-locate workforce, intellectual capital, investment in science, and industrial growth.[24] Finally, students, researchers, and technologists are embedded within institutional, local, state, and national structures that vary in how their policies on international STI engagement yield benefit within a global context.[25,26,27] Because the dynamic global STI landscape offers American institutions, regions, and states the potential to realize tremendous value in a global context, we encourage these groups to freely consider or modify our framework as they develop their international agendas.

As an example, one can consider in Table 1 the international science and engineering internships that yield national economic benefit by bringing into the national workforce U.S. students with globally relevant work skills, cultural experience, and professional networks. Such internships can also provide great benefit at subnational scales. For example, at a state level, public university international engagement, private sector strengths, demography, and geography can make certain regions of the world natural partners. Students returning from internships in those foreign regions are more able to work in culturally diverse teams, are more knowledgeable about business approaches, customs, and markets of countries there, and are plugged into border-spanning networks and partnerships in that region. They can help meet local American needs by using the international skills, savvy, and connections they acquired during their internships to bolster focused international ventures of a state's private sector.

Our final objective is that our framework serves as a call to action that stimulates internationally engaged scientists to better document the positive impacts of their international activities at national, state, local, and institutional levels. U.S. scientists and institutions have strong traditions of free scientific inquiry with international colleagues and of training students from around the world. Many are part of global scientific networks and clamor for facilitation of bottom-up international STI collaboration. Better articulation of the positive impacts of such collaboration is needed to inform national priorities, policies (e.g., on visas, intellectual property, data sharing), and funding (e.g., to globally link students, researchers, institutions, databases, and facilities), as well as to build support for and reduce impediments to international STI engagement at subnational levels.

Broad support is needed at many levels for those in the American STI community who want to "go global." Thus there is an urgent need for scientists to help decision makers and especially citizens understand and value not just the scientific benefits of international research, but also how it meets basic human and national needs.[28] In the "Public Messaging" column in Table 1, we provide model language, as suggested by Alan Alda at the 2014 AAAS Annual Meeting, which we believe is straightforward, compelling, and linked to the lives of the American people.[29] We emphasize outcomes that can motivate domestic action and political consensus and can be conducive to international cooperation (e.g., national pride, economic and social wellbeing, national security, generosity, the value of knowledge, civics). With the language in that column as a guide, we challenge our fellow scientists to describe, in ways that their relatives, neighbors, institutional leaders, and civic leaders can understand, how their collaborating in international science helps America.

A Forward-looking, Dynamic Conversation

We welcome discussion and further exploration of the benefits of international STI engagement by decision makers at all levels and across all sectors, as well as by scientific professional societies and scientists themselves. We see these activities as an essential part of ongoing consideration of how to develop a broad, comprehensive, globally framed strategy for U.S. STI, as well as the supportive strategies at subnational levels. We hope that our framework will contribute to the nation's narrative about how the United States can "lead through collaboration" to build and sustain broad and deep partnerships of mutual interest that keep our scientists and students at the forefront of STI, while bolstering synergistic cooperation for the benefit of America and the world.[30]

Table 1. Organizational Framework for Elucidating Seven Types of Benefits of International Science, Technology, and Innovation Collaboration for America

Seven Types of Benefit and Examples	*Nature of Collaboration*	*Public Messaging*	*Collaborating Entities*
1. Scientific		**International STI Collaboration . . .**	
Lead on "Big" Science/ Atacama Large Millimeter/submillimeter Array Telescope (ALMA)[31]	ALMA, co-funded by NSF, gives U.S. scientists access to a world-class facility in an ideal location in Chile's high desert to study the universe's origin, e.g., 2014 discovery of planet formation around star	...helps advance scientific knowledge by partnering with other nations to develop and use large facilities that must be built outside the United States.	Chile, Europe, Japan, Canada, Taiwan, South Korea
Address Global Phenomena/ Global Earth Observation System of Systems (GEOSS)[32]	GEOSS enables nations to combine their physical, chemical, and biological observations to better understand the global environment.	. . . enables Americans and the world to combine their observations to understand changes that stretch across and affect the whole world.	75 nations
Compare Parallel Trends/ Pollinator assessment by Intergovernmental Science-Policy Platform on Biodiversity andEcosystem Services (IPBES)[33]	The first IPBES global assessment will synthesize research from many countries to help policy makers protect pollinators essential to healthy ecosystems.	. . . allows a global scientific group to study parallel trends in pollinators so the world can protect them and have food security and healthy natural ecosystems.	More than 120 member nations
2. Economic		**International STI Collaboration . . .**	
Accelerate Technology/ International Technology Roadmap for Semiconductors[34]	Industries, governments, and universities cooperate in a pre-competitive setting to reduce overlap and tap collective strengths for rapid progress on new technology and infrastructure.	. . . among governments and researchers to partner with industry to improve efficiency and produce electronic devices that are faster and cheaper.	Europe, Japan, South Korea, Taiwan
Globalize U.S. Workforce/ International science and engineering internships[35,36]	Combining STI internships with language and cultural training helps build a globally engaged and globally competitive U.S. workforce.	. . . gives U.S. young people the international experience they need to get good jobs in the global economy and seeds future collaborations.	Worldwide

Seven Types of Benefit and Examples	*Nature of Collaboration*	*Public Messaging*	*Collaborating Entities*
Jointly Safeguard New Technologies/ Nanotechnology cooperation[37,38]	Costs of nanotechnology-related environmental and health research are shared by many nations, enabling major, safe economic benefits here and abroad.	. . . facilitates sharing the costs of needed environmental and health safety research, so new nanotechnologies can yield better products and safer lives.	OECD Working Party on Nanotechnology
3. Health		**International STI Collaboration . . .**	
Lead on Health Research/ Human Genome Project (HGP)[39]	Sharing HGP work made it cheaper and faster to see the impact of genes on human health, which continues to yield improved U.S. wellbeing, and hundreds of thousands of U.S. jobs.	. . . helps America lead projects too big for one nation; HGP, an international effort, continues to help Americans stay healthy and U.S. biotech industries remain at the forefront.	UK, Germany, Japan, China, France
Control Infectious Diseases/ Smallpox,[40] HIV/AIDS,[41] tuberculosis, Ebola, and malaria[42,43]	Decades of shared global work wiped out smallpox, saving millions of lives. American and global efforts have reduced the huge health, economic, and social costs of other infectious diseases.	. . . contributes to the global fight against such diseases and keep Americans and the rest of the world healthy.	World Health Organiza-tion, many individual nations
Share Healthcare Tools/ Developing-world mobile health tools[44]	Building mobile health tools for developing countries can yield applications that can be used to reach remote U.S. sites and victims of U.S. natural disasters.	. . . enables Americans to help build mobile health solutions in other countries that can also improve the domestic healthcare system.	Developing countries
4. Diplomacy & Development		**International STI Collaboration . . .**	
Strengthen Diplomatic Ties/ Science and Technology Agreements (STAs)[45]	STAs are science diplomacy tools that help scientists work with foreign partners, advancing science, creating goodwill toward America, and building diplomatic relationships.	. . . at the government-to-government level makes collaboration easier, creates goodwill toward America, and helps win allies.	More than 50 countries
Apply Science in Development/ USAID Higher Education Solutions Network (HESN)[47]	HESN links U.S. and foreign students and faculty to bolster STI capacity abroad and bring American innovation to global development challenges.	. . . links U.S. and developing countries to use science to address development challenges and improve life in developing countries.	Developing countries

Seven Types of Benefit and Examples	*Nature of Collaboration*	*Public Messaging*	*Collaborating Entities*
Increase Food Security/ BREAD Program of NSF, Bill and Melinda Gates Foundation[48]	By applying scientific research to agriculture in the developing world, U.S. and host country science partners can help smallholder farmers grow healthier, pest-free food.	. . . combines U.S. generosity and research excellence in agriculture to reduce hunger in developing countries.	Countries in Asia, Africa and Latin America
5. National Security		**International STI Collaboration . . .**	
Maintain Technological Edge/ Department of Defense (DoD) Unmanned Systems Integrated Roadmap[49]	To develop unmanned air, land, and water systems, American scientists work with our allies to assure the most advanced technology and interoperability.	. . . enables America to share research findings with our allies to secure the most advanced technology for U.S. security and better avoid technological surprise.	U.S. allies
Understand Cultural Contexts/ DoD Minerva Initiative[50]	Minerva funds social scientists in international projects that explore how sociocultural factors influence peace and conflict.	. . . among social scientists helps America understand sources of current and future conflict and the paths to peace.	Worldwide
Scan the Horizon/ Global Futures Forum (GFF)[51]	The United States is part of GFF, which shares unclassified perspectives, data, and tools to make sense of emerging and future global security challenges.	. . . allows America to share perspectives, data, and tools with allies to look to the future to understand emerging global threats to national security and new opportunities for global progress.	Many countries
6. Educational		**International STI Collaboration . . .**	
Sustain U.S. Academic Excellence/ Fulbright[52] and PIRE (Partnerships for International Research and Education)[53]	Americans scientists and students abroad get global STI experience, leverage foreign expertise and resources, and share how U.S. schools teach, do research and service, and drive economic growth.[54]	. . . helps U.S. universities tap into global expertise, facilities and phenomena, collaborate with the best and brightest from around the globe, and bring innovative ideas back to the United States.	Worldwide
Build Global Knowledge Networks/ International Research Network Connections program[55]	Linking IT networks to the United States builds collaboration infrastructure, enables global engagement, and provides access to worldwide scientific data.	. . . keeps Americans and their IT systems tied into global networks with the best people and data outside the United States.	Worldwide
Foster Global Learning/ Global Learning and Observations to Benefit the Environment (GLOBE)[56]	At K-12 levels, GLOBE links U.S. and foreign students, via teachers, with scientists worldwide to collect data, learn about science, and be stewards of the Earth's environment.	. . . links K-12 students and teachers around the world with scientists so the next generation understands complex global issues.	113 countries

Seven Types of Benefit and Examples	*Nature of Collaboration*	*Public Messaging*	*Collaborating Entities*
7. Societal		**International STI Collaboration . . .**	
Find Shared Sustainable Balance/ Great Lakes cooperation[57]	U.S. and Canadian scientists and engineers work together to bolster ecological and economic sustainability of vast shared freshwater system.	. . . with Canadian scientists helps keep water, nature, and industry thriving around our shared lakes.	Canada
Ensure Society's Safety/ Earthquake-resistant construction[58]	Collaboration enables joint testing of large-scale structures on Japan's huge "shake table," so Americans and Japanese can engineer safer buildings.	. . . helps Americans use unique research facilities abroad, like Japan's huge "building shake table," to build safe places to live and work.	Japan
Understand and Improve Learning/ BRAIN Initiative,[59,60] (Brain Research through Advancing Innovation Neurotechnologies®)	International collaboration will speed understanding of the human brain and learning, potentially yielding new technology, new jobs, and enhanced learning capacity.	. . . leverages worldwide investments to speed our learning about the brain and learning, to enrich technology, jobs, education, and lives.	Several countries

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Endnotes

1. Hereafter when we use the term "science," we use it as shorthand for "science and engineering."
2. The National Science Board's 2016 Science and Engineering Indicators (Arlington, VA: National Science Foundation, 2016) reported that the United States had 27 percent of world R&D expenditures in 2013. Previous reports (available on the National Science Board's publication website) document 33 percent in 2005 (2008 report), 43 percent in 1997 (2000 report) and 48 percent in 1986 (1989 report).

3. The Institute of International Education's 2013 Open Doors (2013) data on global student mobility trends indicated that worldwide growth of mobile students has increased dramatically over the past dozen years, but the percentage coming to the United States in all fields of study had fallen from 28 percent in the 2000-2001 academic year to 19 percent in the 2012-2013 academic year, with much of the decrease taken up by China, Germany, and Canada; by 2014-2015 the U.S. had seen a partial rebound to 22 percent, due in part to strategic initiatives by the U.S., Mexican and Brazilian governments; 2015 Open Doors.
4. C. S. Wagner, H. W. Park, and L. Leydesdorff, "The continuing growth of global cooperation networks in research: A conundrum for national governments," PLOS One (2015), doi: 10.1371/journal.pone.0131816.
5. A. Mazloumian, D. Helbing, S. Lozano, R. P. Light, and K. Börner, Global multi-level analysis of the "Scientific Food Webs," Scientific Reports 3, no. 1167 (2013), doi: 10.1038/srep001167.
6. National Science Board, International Science and Engineering Partnerships: A Priority for U.S. Foreign Policy and Our Nation's Innovation Enterprise (Washington, DC: The National Academies, 2008).
7. National Research Council, Beyond "Fortress America": National Security Controls on Science and Technology in a Globalized World. (Washington, DC: National Academies Press, 2009).
8. National Research Council, U.S. and International Perspectives on Global Science Policy and Science Diplomacy, Report of a Workshop (Washington, DC: National Academies Press, 2012).
9. National Research Council, Strategic Engagement in Global S&T: Opportunities for Defense Research (Washington, DC: National Academies Press, 2014).
10. National Research Council, Diplomacy for the 21st Century: Embedding a Culture of Science and Technology Throughout the Department of State (Washington, DC: National Academies Press, 2015)
11. M. Jacob and V. L. Meek, "Scientific mobility and international research networks: Trends and policy tools for promoting research excellence and capacity building," Studies in Higher Education 38 (2013): 331–44.
12. R. B. Freeman and W. Huang, "China's 'Great Leap Forward' in Science and Engineering," National Bureau of Economic Research Working Paper no. 21081 (April 2015).
13. Many other nations, large and small, have already turned to such a course, and many seek to partner with the United States. Examples of regional or national approaches and rationales for international STI cooperation include European Commission, International Cooperation in Science, Technology and Innovation: Strategies for a Changing World, Report of the Expert Group established to support the further development of an EU international STI cooperation strategy (2012).
14. The scope and trajectory of STI internationalization at U.S. institutions of higher education is not well documented; a recent survey found that about one-third of institutions polled had strategic international plans that explicitly mention science fields, and less than 5 percent had plans where science fields were prominently included. See S. B. Sutton and E. E. Lyons, "Unintentional diplomats: International science engagement and science diplomacy by U.S. higher education institutions," Association of International Education Administrators, 2014.
15. G. Hane, "Science, technology and global reengagement," Issues in Science and Technology 25, no. 1 (Fall 2008).
16. The recent establishment of the interagency Subcommittee on Topics in International Science, Technology and Innovation (TISTI; under the White House's National Science and Technology Council) to address issues related to federal international STI activities could provide a greater opportunity to harmonize across the federal STI enterprise.
17. We recognize the importance of the private sector in international STI collaboration but it was beyond the scope of this endeavor and our expertise to provide detailed treatment of the benefits of such STI collaboration.
18. The report, European Commission, Drivers of International Collaboration in Research (2009) presents some similar categories and so was a useful comparison against which to compare our U.S. typology. Although our focus is primarily on research collaboration, we include other STI examples, e.g., on education, synthesis and assessment, and public health interventions.
19. The "Gathering Storm" reports (The National Academies. Rising Above the Gathering Storm, Revisited: Rapidly Approaching Category 5 [2010] and the original 2006 report cited therein) which focus on U.S. competitiveness, are seemed written for domestic audiences, and aimed to catalyze national investment in domestic STI education and research. In doing so, they tended to overlook positive contributions of international collaboration and portrayed the rest of the world primarily as a source of excellent students who need visas to come and/or stay, and as posing an economic challenge to the competitiveness of U.S industry.
20. B. Hecht, "Collaboration is the new competition," Harvard Business Review (January 10, 2013).
21. National Research Council, Beyond "Fortress America."
22. C. S. Wagner, The New Invisible College (Washington, DC: Brookings Institution, 2008).
23. R. Florida, "The world is spiky," Atlantic Monthly (October 2005) 48-51.
24. R. Dobbs, J. Manyika, and J. Woetzel, No Ordinary Disruption: The four global forces breaking all the trends (New York: Public Affairs, 2015).
25. A. Hogan, K. Zippel, L. Frehill, and L. Kramer, "Report of the International Workshop on International Research Collaboration," NSF-funded workshop report (2010).

26. K. Fischer, "U.S. seen as weak on global research collaboration," New York Times, July 20, 2014.
27. The National Academies, Examining Core Elements of International Research Collaborations (Washington, DC: National Academies Press, 2011).
28. The case studies published by the National Academy of Sciences in its "Beyond Discovery™: The Path from Research to Human Benefit" project are remarkable for their clear communication of how technological and medical advances have improved American lives.
29. Following the advice Alan Alda presented at the 2014 AAAS Meetings (http://www.aaas.org/news/alan-alda-good-communication-can-keep-scientists-and-public-committed-relationship, Chicago, IL, February 2014), we chose as a first step to present "stories" rather than to present data. The framework could advance the development of metrics for measuring impacts of international collaboration, which are being developed, for example, for students participating in international research projects, for research collaborations, and for economic impacts.
30. E. W. Colglazier and E. E. Lyons, "The United States looks to the global science, technology, and innovation horizon," Science & Diplomacy (July 2014).
31. ALMA press release.
32. GEOSS website.
33. Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) Pollinators, pollination and food production assessment.
34. International Technology Roadmap for Semiconductors website.
35. Sigma Xi, "Assuring a Globally Engaged U.S. Science and Engineering Workforce," NSF-funded Sigma Xi workshop report (2006).
36. J. M. Grandin and E. D. Hirleman, "Educating Engineers as Global Citizens: A Call to Action; A Report of the National Summit Meeting on the Globalization of Engineering Education" (2009).
37. Long-term cooperation has occurred within the Organisation for Economic Co-operation and Development (OECD); see OECD, "Science and Technology Policy: Nanotechnology," Working Party on Nanotechnology (2014).
38. More recently the United States and the European Commission (European Research Area) issued coordinated calls for proposals to encourage United States–European collaborations on environmental and health effects of manufactured nanomaterials (http://www.nsf.gov/pubs/2015/nsf15022/nsf15022.pdf).
39. See the National Institutes of Health Human Genome Project website.
40. R. I. Glass, "What the United States has to gain from global health research," Journal of the American Medical Association (September 4, 2013).
41. The President's Emergency Plan of AIDS Relief (PEPFAR).
42. The President's Malaria Initiative (PMI).
43. The Global Fund to Fight AIDS, TB, and Malaria.
44. Mobile Health research agenda.
45. B. M. Dolan, "Science and Technology Agreements as tools for science diplomacy: A U.S. case study," Science & Diplomacy (2012).
46. The Pew Global Attitudes Project has long shown that people worldwide admire the United States for its science and technology at levels considerably higher than their attitude toward the United States in general.
47. See the United States Agency for International Development Higher Education Solutions Network website.
48. National Science Foundation BREAD website.
49. Department of Defense Unmanned Systems Integrated Roadmap FY2013-2038 website.
50. Department of Defense Minerva Initiative website.
51. Global Futures Partnership website.
52. Fulbright Programs website. Note: Fulbright programs also bring foreign students and scholars to the United States; such exchanges enrich both foreign and U.S. campuses and build lasting networks and STI expertise.
53. National Science Foundation Partnerships in International Research and Education (PIRE) website. PIRE supports top-notch international science and engineering research projects that also provide U.S. students with well-mentored international research experiences and strengthen the capacity of U.S. universities to engage in international STI collaboration.
54. The "Gathering Storm" reports (The National Academies. Rising Above the Gathering Storm, Revisited: Rapidly Approaching Category 5 [2010] and the original 2006 report cited therein) focused on U.S. competitiveness. It was aimed at catalyzing greater national investment in domestic STI education and research and government policies that facilitate innovation. Because of the focus on economic competitiveness, the benefits of international STI collaboration to the U.S. STI enterprise may not have been highlighted to the degree it deserves.www.irnclinks.net.
55. Global Learning and Observations to Benefit the Environment (GLOBE) website; GLOBE is a joint program of National Aeronautics and Space Administration, National Science Foundation, National Oceanic and Atmospheric Administration, and the Department of State.

56. Environmental Protection Agency Great Lakes Water Quality Agreement with bilateral cooperation on science, policy, and action.
57. National Science Foundation Network for Earthquake Engineering Simulation (NEES) information.
58. The BRAIN Initiative (Brain Research through Advancing Innovative Neurotechnologies) is a public-private effort involving multiple U.S. agencies, including National Science Foundation, National Institute of Health, and Defense Advanced Research Projects Agency.
59. National Science Foundation welcomed international collaboration in the BRAIN initiative, noting in particular the more than $2 billion European Union investment in the Human Brain Project: http://www.nsf.gov/pubs/2014/nsf14082/nsf14082.jsp