Collaborating to Solve National Science and Technology Challenges in a Time of Scarcity

by Ian G. Brosnan and Jonathan Stock

In late 2014, the U.S. Geological Survey (USGS) signed an interagency agreement to explore scientific collaborations with the National Aeronautics and Space Administration's (NASA)'s Ames Research Center (ARC), which was followed by a second agreement in 2016 to begin moving the USGS science facilities in Menlo Park, California, to the nearby ARC campus.[1,2] A primary goal of both parties to these agreements has been to solve national challenges collaboratively using innovative new tools, while aligning scarce funding to provide greater public value. However, techniques to stimulate interagency collaboration in science and technology (S&T) have not been well described, and our aim in this article is to describe what we have learned about activities and structures, their implementation, and the necessary leadership required to stimulate interagency S&T collaboration at the research-performing level.

Interagency S&T collaboration is a particularly important issue because the fiscal outlook for the U.S. government is not favorable for growth of the federal S&T enterprise. In 2016, federal spending exceeded revenues by more than half a trillion dollars, up from $439 billion in 2015; this trend is generally considered unsustainable, and some combination of reduced spending and increased revenue will likely be required to put the nation on a secure fiscal footing.[3] In this light, it is difficult to see any increases in federal spending on research and development (R&D), including S&T, which has been flat or declining since the early 2000s.[4] At best, R&D budgets will remain flat,

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and alternative approaches will be needed if the S&T enterprise is to deliver on its full potential.

Innovation is at the heart of S&T and can be brought about when different fields of knowledge are brought together in search of creative solutions to new challenges.[5] A dearth of resources for new S&T efforts and the tendency of existing programs to ossify means that flat or declining budgets will act to reduce the number of new fields of knowledge available to be brought together within individual federal science agencies. However, the reduction and elimination of duplicative work in the federal government should also ensure that there are disparate fields of knowledge across the science agencies.[6] By bringing these disparate fields together, interagency collaboration at the research-performing levels could serve to blunt some of the impact of flat or declining budgets.

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However, despite its promise, stimulating collaboration at the performing levels of research organizations is not easy. Science and technology are frequently esoteric, unpredictable, and slow. Its practitioners are well educated and enjoy commensurate levels of autonomy and hierarchical flattening. Furthermore, interactions between researchers and bureaucracy often militate against collaboration, particularly top-down, directed efforts. All of this creates difficulty in identifying and initiating collaborations.

Characteristics of the Federal S&T Enterprise that Affect Collaboration

The esotericism of S&T stems from its fundamental nature. The work that makes up the body of most research careers in S&T includes the application of the scientific method to questions falling within some accepted scientific paradigm, where the scientific method includes formulating hypotheses; developing, proposing, and implementing rigorous tests of these hypotheses; collecting and interpreting the results; and disseminating them through scientific conferences, meetings, and peer-reviewed publications.[7] The longer a scientific paradigm lasts, the more refined the questions become, and the more inaccessible it becomes to all but experts in the field. In other words, it becomes increasingly esoteric.[8]

For example, in 1635 Pierre Gassendi estimated the speed of sound in air to be 478 meters per second by comparing the time between the sighting of the flash of a firearm and the arrival of the sound of its firing.[9] Most of us can understand Gassendi's contribution to the field of acoustics. In contrast, consider a recent publication in the *Journal of the Acoustical Society of America* by Leão-Neto et al., wherein the scattering of a longitudinal Bessel beam of arbitrary order by a sphere embedded in an isotropic solid matrix is theoretically analyzed.[10] Few of us could explain Leão-Neto et al.'s work and why it represents a sufficient advancement in the field of acoustics to be published in a leading scientific journal. So, although there may be brief periods following the introduction of a new paradigm when a field of science or technology is more accessible, in the modern period it is probably still only available to a few technical professionals.[11]

Science and technology development is also unpredictable. It is difficult, often impossible, to know *a priori* what lines of questioning or new techniques and processes will advance our scientific understanding of a phenomenon, or even what experiments will be successful. Failure is the norm, although it may not be widely acknowledged.[12] The fact that an apparent failure can result in a significant advance makes this more complicated. The canonical example is penicillin, an antibiotic drug that was discovered due to poor laboratory practices. Alexander Fleming left an uncovered petri dish sitting next to an open window, where it became contaminated with *penicillium* spores that eradicated the bacteria he was studying. His apparent error, however, led him to realize that an anti-bacterial drug could be separated from the spores, and penicillin has subsequently saved millions of lives.[13] Conversely, successful ideas may languish if they are ahead of their time. Alfred Wegener applied geology and paleontology to propose continental drift in 1912, but the scientific community was not prepared to accept his ideas until additional evidence was brought to light, at which point the theory of plate tectonics was developed and widely accepted in the 1960s.[14]

Finally, scientific and technological advances have potentially long gestation times. Even in fast-paced fields of S&T, it may take decades for a line of inquiry to prove fruitful. The R&D work that ultimately led to NASA's Kepler/K2 mission to find Earth-sized worlds orbiting alien stars was rejected in peer-review many times during its 20-plus years of development. However, since its launch in 2009, it has become one of the world's greatest scientific successes. The mission has launched hundreds of scientific careers and spawned more than 2,000 publications that have subsequently been cited more than 65,000 times in dozens of scientific fields.[15] Notably, Kepler/K2 advanced incrementally through various competitively-selected R&D grants; it was not selected at inception for a lifetime of funding.

As might be expected from the discussion above, advances in S&T require practitioners with a high level of education and expertise who operate fairly autonomously and are trained and expected to do so from the graduate level of their education onward.[16] This level of autonomy tends to flatten hierarchies, and the best research institutions encourage this flattening, whether or not it is reflected in its organizational charts.[17] However, federal research-performing organizations do have to balance the controls that come with the large social costs of their research enterprise with the level of individual discretion that is essential for innovation and discovery.[18] However, if left unchecked, bureaucratic controls seem to grow inexorably and with them the tendency to temper and routinize every facet of the enterprise. This is a death-knell in the S&T environment.[19] As a consequence of this tension, researchers, like many professionals, will resist anything they perceive to be bureaucratic interference, and any efforts to stimulate collaboration that appear to be an exercise in administrative control or inhibit research autonomy are unlikely to be well received or successful.

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Stimulating Interagency S&T Collaboration

Highly autonomous and hierarchically flat organizations that are culturally resistant to management interventions and perform esoteric, unpredictable work over potentially long-time horizons present clear challenges to anyone looking to stimulate collaboration. James Q. Wilson observed that such organizations are best managed by nurturing adherence to the wider professional norms of its members.[20] Similarly, we believe that the best way to stimulate collaboration in S&T organizations is through activities that are aligned to the professional norms of scientific and technical staff.

We have found that cross-agency seminar announcements, invited talks, integration of like-minded interest groups, advisory committees, and seminars and workshops organized around common research themes, all paired with a small amount of funding to seed emerging collaborations, can generate new and exciting projects that would not have been possible without interagency partnership. Each of these activities is a normal part of technical discourse in S&T organizations, fit to a slightly different purpose.

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Appropriate resourcing is a necessary condition for a successful interagency collaboration, but to stimulate S&T collaborations, it is also important that resources are distributed in a recognized and acceptable manner. Most research-performing organizations have internal R&D funds for exploratory work that has potential to develop into proposals for larger streams of funding. These internal funds are usually small, often in the range of $50,000 to $100,000 and are distributed over one or two years. This is also probably the right level for stimulating collaborations at the research-performing level because the transaction costs for potential collaborators are low (especially if proposal requirements are limited to a few pages) and, in the case of failure, the opportunity costs in terms of the time and effort put into the collaboration are also small.

A competitive, peer-reviewed process should be used to award these funds because this approach is aligned with the professional norms of the scientific community and sustains trust. Peer-review also overcomes some of the difficulties of esotericism and unpredictability by drawing on deep and often domain-specific expertise to evaluate the most promising collaborations that can reasonably be expected to be successful. Furthermore, the outcomes of the review process can be used to improve weaker proposals for future submissions.

NASA and USGS have both used these small funds to support interagency collaboration that targets significant national challenges. Early in 2013, a diverse group of USGS scientists (including co-author Stock) approached the USGS Director Marcia McNutt and Deputy Director Suzette Kimball with a proposal to connect scientists with technology opportunities outside the USGS. This led directly to the creation of the USGS Innovation Center at Menlo Park, funded at approximately $500,000 annually to fuel partnerships that would bring new technologies into USGS to solve national challenges. The creation of the Innovation Center provided an opportunity for USGS scientists to propose small projects, less than $70,000 each, with technology partners. A short, four-page proposal template with simple, identified rating criteria kept the opportunity costs for proposals low, and proposals are reviewed and selected by a panel of USGS Senior Scientists. The Innovation Center approach informed the design of the NASA ARC Orbit-to-Core (O2C) fund, which was introduced in 2017 with the goal of seeding innovative science collaborations with partners at one of the six science centers at USGS's Menlo Park campus. In addition to being technically and fiscally sound, proposers were required to describe how a collaboration with USGS would advance NASA's S&T priorities, with the strongest proposals demonstrating ideas that advanced both agencies' missions. Senior NASA scientists, engineers, and managers reviewed and scored the proposals.

Although funding is a necessary condition for collaboration, it is not sufficient. Esotericism, unpredictability, and different timetables can make finding a partner with the right technical skills and an aligned interest challenging. We have taken several approaches to overcome this problem. One approach is the USGS Innovation Center's annual hosted workshops where scientists are invited to talk about important observational or analytical gaps, and engineers and technologists to talk about emerging tools that span gaps. Serendipitous and curated conversations at these workshops have led to many of the collaborations between USGS and NASA that are funded by the USGS Innovation Center.

The USGS Innovation Center articulated the scientific value for the move to Moffett Field, so the NASA and USGS campuses first undertook the charter of a local science advisory committee that meets to identify and connect technical staff with collaborative opportunities and advise management of the support necessary to nurture these opportunities. One of the first recommendations from the committee was the institution of intra-campus, interagency, S&T seminar announcements. Once the logistics of this approach were resolved, the effort generated immediate results. First, attendance at some seminar series nearly doubled, which spoke to the potential for common interests across the research campuses. Second, teams that would not normally be expected to find common ground began to engage each other. For example, the Kepler/K2 project scientist logged into a virtual seminar describing USGS's efforts to communicate complex scientific hazard information to the public and realized USGS's techniques could be applied to communicate the challenges and successes of the Kepler/K2 mission.

Research presentations aimed at raising the visibility of specific capabilities and interests of each agency have also borne fruit. Researchers at the USGS Western Geographic Science Center are actively engaged in a research partnership with NASA ARC's Intelligent Systems Division to apply cutting-edge, machine-learning techniques to the study of carbon flux across the state of California. This idea germinated after NASA ARC scientists spoke at USGS about the role of machine learning and other artificial intelligence methods in NASA's exploration mission and how these techniques can be applied to common categories of questions.

Linking interest groups across the two agencies has also proven popular and effective. The NASA and USGS early-career groups now meet regularly, and during these interactions, a team of early-career researchers launched a partnership to fuse USGS point-based mineral resource and geochemical data with NASA remote sensing data, machine-learning tools, and high-performance computing resources to develop new mineral deposit maps.

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For several years, the agencies have also hosted joint NASA/USGS science poster sessions. Poster sessions are common at scientific meetings and provide for direct interaction between scientists displaying their research results in a poster format, and audience members moving among the posters. During the first of these joint poster sessions, a NASA aeronautics researcher, using the principles of compound eyes to develop a blade deformation sensor, met USGS researchers who realized the technology could be applied to reduce the costs of monitoring and measuring deformation of the earth associated with earthquakes and volcanoes. This connection led to a successful USGS Innovation Center proposal for funding to develop the idea, and this remains an active collaboration between the two agencies.

Not every effort to stimulate collaboration has been successful. Despite self-selected attendance by interested scientists, several interagency meetings to target specific research opportunities announced in the annual omnibus NASA Research Announcement, Research Opportunities in Space and Earth Science were not successful in generating interagency research proposals. We suspect that these sorts of direct interventions are either too far from the norms of our scientists or too close to proposal deadlines (generally, less than a year) for the necessary trust and experience to have been built between the attendees. These meetings have, however, served to familiarize staff members with their counterparts, as well as the funding opportunities, and so they may bear fruit in the long run.

By creating an environment for collaboration that meets expected scientific norms, backed by modest resourcing, the agencies have stimulated collaborations that could not have been easily predicted or successfully directed. Additional examples include improvements in wildlife tracking systems by incorporating NASA next-generation micro-electronics, 3-D batteries, and novel sensors with emerging small satellite constellations; automated production of flood maps from a fusion of machine learning with daily Earth imagery; application of autonomy to more efficiently and safely collect field data from volcanoes, rivers, gas seeps, and wildfires; and an effort to determine, from terrestrial anaerobic microbial analogs, which organic compounds, if detected, could only indicate life on the ocean moons of Europa and Enceladus.

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Leader Requirements

Stimulating interagency S&T collaboration requires a different style of leadership than is usually applied in government program and project management. Given the nature of S&T and the degree of autonomy enjoyed by its practitioners, engaged leaders who are alert for opportunities to align interests and provide help where they can, but who also have the patience to wait for the right opportunity to do so, are more likely to be effective.[21] An element of the success of many of the partnerships described above has been a degree of curation by local USGS and NASA leadership at all levels who recognize and promote aligned interests across the two agencies and then step back from the process once the principal investigators have established strong contacts. This influence-dominated leadership approach recognizes the autonomy inherent in S&T and creates motivated teams with strong project ownership, but also allows for management to perform its vital role of ensuring that new efforts are aligned with larger agency goals and objectives.[22]

Leadership in this context has parallels with a well-studied role in S&T institutions, that of the gatekeeper. As Michael Tushman has noted, information transfer is simultaneously essential for innovation and extremely difficult in an intra-organizational context because the internal efficiencies created by a common language make it difficult to communicate externally.[23] In the same way that the U.S. and England are sometimes described as two nations divided by a common language, NASA and the USGS have a shared interest in Earth science and its associated applications in space science, but their size, operational domains, internal processes, political pressures, culture, and language pose barriers to communication and thus collaboration.

Therefore, boundary-spanners who understand and can communicate in each organization play an important role in linking each institution's internal communications to external sources of information and enabling collaborations that can lead to true innovation.[24] Jain et al. note that gatekeepers frequently assume their roles informally because they are technically and socially adept and stay abreast of external developments through personal and professional communications. So, in addition to some aptitude for influence leadership, leaders in interagency S&T collaboration should demonstrate these same characteristics.[25]

Jain et al. also highlighted a tension between formally appointing gatekeepers, or simply encouraging and rewarding the necessary behaviors wherever they occur.[26] In the context of interagency S&T collaborations, the right approach probably depends on the maturity of the context. For example, NASA and USGS in Silicon Valley have a history of collaboration, but it is dated, and many of the participants have retired or are on the cusp of doing so.[27] Thus, the move of the USGS onto the NASA campus represents nearly a fresh start and, in this case, liaisons were appointed to fill much of the gatekeeping role. However, it may prove that after these initial efforts, a more informal encouragement of a greater number of gatekeepers will be a sufficient and preferred approach.

Conclusion

The characteristics of the S&T enterprise, including its esotericism, unpredictability, and potentially long time-horizons, coupled with the attendant high levels of aptitude, autonomy, and wariness of bureaucracy among its practitioners, will always pose challenges to leaders charged with stimulating interagency S&T collaborations. However, by remaining cognizant of the value of influence leadership and gatekeeping and focusing their efforts on activities aligned with the professional norms of the S&T community, leaders can stimulate interesting and exciting interagency collaborations that deliver significant public value. However, they should also be mindful that the potentially longtime horizons in S&T also mean that it may take time for new collaborations to emerge, and that even for apparently obvious collaborative opportunities, the necessary alignments in funding and career cycles may require additional time.

Finally, as we noted in the introduction, the conditions for successful interagency collaboration have been well documented. Earle et al. provide an excellent summary of best-practices, such as the need for management structures to support planning and execution, including, *inter alia*, documented roles, responsibilities, policies, and procedures, as well as mechanisms to monitor, evaluate, report, and account for results.[28] Earle et al. also highlight key findings from academia regarding intangible conditions such as executive-level leadership support, trust, legitimacy, and motivation.[29] We can attest that these conditions must be emplaced alongside efforts to stimulate collaboration for them to be successful. ***IAJ***

NOTES

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