Integrating Open Innovation into the Core of Federal R&D Strategy

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Abstract: How government conducts and supports research and development (R&D) is evolving. Open Innovation (OI) includes a new set of R&D approaches that change what topics are possible to study, the types of institutions and individuals that can participate, project timelines and formats, perceived boundaries of disciplines, and even patterns of research progression. OI provides the federal R&D enterprise with expanded options to accelerate the pace of discovery and application and to recruit diverse groups to solve R&D needs that intersect multiple traditional disciplines. Systematically integrating OI into federal R&D strategy alongside traditional research will allow government to more nimbly and effectively respond to today's challenges.

I. Open innovation within federal R&D

The United States Federal Government has a large role in the domestic scientific enterprise, funding roughly 25% of the country's R&D (AAAS 2016). R&D "comprises creative work undertaken on a systematic basis to increase the stock of knowledge… and… to devise new applications" (CRS 2017). Since World War II, a primary strategy of the Federal R&D enterprise has been to competitively fund grants and contracts to address research themes or technical needs. This approach of funding R&D through grants and contracts, as well as directly conducting R&D within federal agencies, is hereafter referred to as the "traditional model". This model has enabled foundational discoveries and advances in transportation, medicine, genomics, energy, defense, space, and computing (Singer 2014). Scientific and technological advances have accelerated the pace of innovation and development cycles and created a contemporary context that enables and necessitates new modes of R&D.

Widespread technological proficiency has created an environment in which startups and individuals have unprecedented access to computing power, prototyping capabilities (e.g., 3D printing), shared research laboratories, and communication networks (Sia and Owens 2015). In parallel, R&D has shifted to become more open, distributed, and collaborative (Kogut and Metiu 2001). From this modern R&D ecosystem has risen the paradigm of Open Innovation (OI). OI "is a more distributed, more participatory, more decentralized approach to [problem solving], based on the observed fact that useful knowledge today is widely distributed, and no [organization], no matter how capable or how big, could innovate effectively on its own" (Chesbrough 2011). OI facilitates systematic exploration and integration of input from sources beyond core project participants, both external and internal to an organization (Chesbrough 2003).

In the 2000s, some federal R&D programs expanded to align with this more open innovation ecosystem and began to broadly adopt OI as a means to accelerate research and take on previously intractable problems. With OI came the adoption of new approaches to support fast exploration of ideas, novel connections across disciplines, and increased participation by previously underused and excluded pools of talent. OI by government is in a period of high growth (Gustetic 2017), aided by recent policy (15 USC 3719) and increasingly formalized infrastructure. As a result, federal R&D is evolving in ways that are reshaping science: dramatically shifting the topics studied, types of participants, project formats, and even patterns of research progression. This article explores the use of OI in federal R&D and identifies policy and institutional areas of need to ensure that the federal R&D enterprise can efficiently and effectively take full advantage of OI to solve today's urgent and complex problems.

II. R&D approaches for the 21st century

Many different OI approaches are used by the Federal Government (GAO 2016). Here we present a representative selection of approaches illustrating how incentive prizes, accelerators, and crowdsourcing and citizen science operate in practice and the kinds of problems these approaches help government solve.

i. Incentive prizes

Incentive prizes are competitions with monetary or non-monetary incentives designed around well-defined problems with undefined solutions and/or an unknown group of appropriate problem-solvers (OMB 2010). Since 2010, the Federal Government has launched more than 740 prizes (Challenge.gov 2017).

Example: Transform Tox Testing Challenge

Government has invested heavily in technology to rapidly screen chemicals and predict how they may affect humans. Current techniques cannot screen for the different forms a chemical can turn into after being ingested. The National Institute of Environmental Health Sciences, National Institutes of Health, and Environmental Protection Agency (EPA) launched the Transform Tox Testing Challenge to stimulate the market to fill this critical gap in chemical screening technologies. Tox Test attracted commercially viable ideas, including companies that specifically moved into the technology space to compete. Leading solutions were awarded cash prizes to spur development. Using an incentive prize allowed the government to spark rapid development of new technologies alongside traditional grants and internal research programs (NAS 2017).

ii. Accelerators

Accelerators are a mechanism to identify "winning" ideas more quickly and help them come to fruition (SBA 2014). Accelerators achieve this by selectively investing in R&D and aligning support and resources to expedite R&D from prototype to market-ready in a brief span of time.

Example: Ebola Grand Challenge

During the 2014 Ebola outbreak, many public health workers were exposed to the virus due to inadequate personal protective equipment (PPE) (WHO 2015). The US Agency for International Development and Centers for Disease Control and Prevention led the Fighting Ebola Grand Challenge for Development to accelerate innovation and quickly identify solutions for health care worker needs. Selected from a pool of over 1,500 submissions, winning ideas addressed a range of gaps in our near-term and long-term global response capacity, including PPE design. A set of newly designed suits were produced through a combination of crowdsourcing, hackathons, and partnerships. In 2015, a winning suit design from Johns Hopkins University was commercialized by DuPont (DuPont 2015).

iii. Crowdsourcing & Citizen Science

Crowdsourcing and citizen science are approaches in which members of the public contribute to scientific inquiry and discovery (citizenscience.gov). Crowdsourcing and citizen science are increasingly being implemented in government R&D efforts to enhance scientific research, address questions otherwise untenable due to scale, provide hands-on STEM learning and increase STEM literacy, and increase civic engagement to address societal needs (Holdren 2015).

Example: Crowdsourcing apps for natural disasters

New technologies allow the public to quickly share detailed observations with the US Geological Survey (USGS). USGS has developed online crowdsourcing apps that enable the public to contribute real-time, on-the-ground observations about natural disasters such as earthquakes (*Did You Feel It?*), landslides (*Did You See It?*), and volcanic eruptions (*Is Ash Falling?*). Sensor networks do not cover many areas of the United States, even areas prone to natural hazards, making volunteer observations and reporting a vital resource for assessing the frequency and intensity of hazards (Baum et al. 2014).

II. Open innovation is changing outcomes and impacts of R&D

Among other advantages, OI can "lead to scientific and technological breakthroughs under unusually high time and resource constraints" (Lifshitz-Assaf 2016). In the contemporary era of constrained federal R&D funding, more researchers are turning to OI. Based on the National Science Foundation's[1] award database (nsf.gov/awardsearch), an increasing number of projects that incorporate OI approaches have received federal funding over the last two decades. For example, performing a keyword search on the terms "citizen science" and "public participation in science" at nsf.gov/awardsearch showed that just 23 awards were given in 2012, in contrast with 788 awards in 2018.

While different taxonomies have been proposed (Mitchell et al. 2014), OI approaches are marked by five key functions: *1) expanding the range of approaches, 2) expediting timelines, 3) rewarding outcomes, 4) broadening participation, and 5) expanding scale.* Most OI projects are designed to leverage more than one function, making them simultaneously powerful and complex. Below we briefly define each function and provide examples illustrating the varied ways OI is changing what is possible in government R&D.

OI *expands the range of approaches* to problem solving by focusing on solutions without predetermined approaches, making the process more open to how participants solve problems.

Example: INSTINCT Challenge

The Intelligence Advanced Research Projects Activity (IARPA) funds high-risk, high-reward research benefiting the US Intelligence Community. IARPA launched the INSTINCT[2] Challenge to improve predictions of whether a person would keep a promise based on their partner's neural, physiological, and behavioral signals in an experimental setting. At the time, behavioral science analytics were advancing dramatically (Fanelli and Ioannidis 2013; O'Boyle, Banks, and Gonzalez-Mulé 2017). Preliminary analyses of data collected from volunteer research participants suggested signals collected from one person might have untapped potential to predict trustworthiness in others. IARPA offered cash prizes for solutions that could improve upon existing algorithms.

While a better algorithm was valuable in and of itself, the central value of the INSTINCT Challenge came from learning more about where potential for improvement lay. The winning algorithm demonstrated untapped predictive power in some areas (e.g., heart rate, decision times) and steered researchers away from unproductive lines of inquiry. In addition to magnifying the value of data from a multi-year traditional R&D effort, lessons from INSTINCT have facilitated further IARPA incentive prizes on topics like speech recognition, 3D mapping, and fingerprint recognition. INSTINCT and other prizes have allowed IARPA to map out the state of the science before pushing forward, quickly test pilot solutions, and reach out to new groups of solvers. Across many agencies, lessons learned from an expanded range of approaches have helped calibrate goals for multi-year programmatic efforts and focused problem solving to break through barriers highlighted by broader studies (Kalil 2017).

OI *expedites timelines* by compressing the time between problem identification and solution development. Some OI approaches motivate participants by *rewarding outcomes*. Instead of selecting approaches and financing proposed research up front, the incentive structure is flipped

[1] NSF is the largest federal funder of non-medical research.

[2] INSTINCT stands for Investigating Novel Statistical Techniques for Identifying Neural Correlates of Trustworthiness.

and the sponsoring agency or agencies only pay for successful outcomes.

Example: Brain on a Chip

EPA runs an accelerator called Pathfinder Innovation Projects (PIPs), which incentivizes EPA scientists to pursue transformative research outside the standard research planning structure. Projects are initially selected by external panels. Competitive performance in early work is then rewarded with additional funding to prototype and implement technologies, with a goal of shortening the time from idea to application. With more than 600 scientists applying since 2011, PIPs have become one of EPA's cornerstone innovation activities.

A project dubbed Brain on a Chip exemplifies the PIPs program. Only about 100 of the thousands of chemicals in commerce have been tested for developmental neurotoxicity because testing is prohibitively expensive and time consuming (Makris et al. 2009). PIPs accelerated a project to develop a fast, inexpensive tool to differentiate chemicals that affect brain development from those that do not. The approach used activity in neuron networks grown on microelectrode arrays. While testing in animals costs up to $1 million per chemical (Smirnova et al. 2014), this new screening approach can be done for roughly $500 per chemical. The PIPs program is providing the structure and incentives to quickly scale this project as an economical approach to screen large numbers of chemicals for neurotoxicity at a fraction of current costs.

OI *broadens participation* by soliciting perspectives from across scientific and technical disciplines, as well as from the private sector and members of the public, to increase the number, diversity, and range of expertise of people and organizations working on a problem. OI *expands scale* by leveraging modern networks and technologies to address questions that were previously impractical because of geographic, computational, temporal, or human scales.

Examples: CoCoRAHS and Zooniverse

NSF and NOAA fund[3] the Community Collaborative Rain, Hail and Snow Network (CoCoRAHS) to enhance weather and climate models. Today, 20,000 volunteers across all 50 states and US territories participate in online training, then upload daily precipitation measurements. Volunteer-reported data has revealed dramatic gradients in precipitation across areas that weather station networks and models were previously unable to resolve. The US Department of Agriculture's Risk Management Agency now uses CoCoRAHS data in its crop insurance programs (PRISM 2017), while farmers have direct access to the same data in real time.

In another case, NSF funded[4] a proposal to address the challenges of ever-growing volumes of data; this proposal led to the development of Zooniverse. Zooniverse crowdsources data processing to anyone in the world with internet access. Since 2007, Zooniverse has supported 100+ projects, a community of 1.6+ million volunteers, and 120+ peer-reviewed publications[5]. During the 2017 hurricane season, Zooniverse hosted satellite images of Caribbean regions hit by hurricanes. Within days of the hurricanes, people at 10,000 unique IP addresses analyzed the equivalent of what a satellite imaging expert could process in 1.5 years to map flooding, structural damage, blocked roads, and the location of people in temporary shelters in order to inform disaster relief efforts (Simmons 2017).

The four examples above demonstrate a range of ways OI has successfully operated alongside the traditional R&D model, redefined patterns of research progression, expanded participation in R&D, and changed perceptions of qualified problem-solvers to achieve new and previously untenable outcomes for government R&D. Next, we discuss some of the barriers OI faces in government.

IV. Barriers to integrating open innovation into the federal R&D strategy

Increased experimentation and adoption of OI alongside the traditional R&D model is an important path toward enabling government to more nimbly respond to problems. However, integration of OI into federal programs has encountered significant barriers. Here we examine the influence of policy, resources, and people on the use of OI.

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[3] Public grants NSF-0229723, NSF-1010888, NOAA-NA06SEC4690004, and NOAA- NA10SEC0080012.

[4] Public grant NSF-0941610.

[5] A complete list of Zooniverse publications is maintained at https://www.zooniverse.org/about/publications.

i. Policy barriers
The America COMPETES Reauthorization Act of 2010 gave federal agencies authority to use incentive prizes. In 2017, the American Innovation and Competitiveness Act granted agencies explicit authority to conduct projects involving crowdsourcing and citizen science (15 USC 3719). These enabling policies facilitate agency use of new R&D approaches and encourage OI integration into R&D strategies.

However, insufficient data on participation, demographics, impact, reach, and return-on-investment of OI programs and projects are a barrier to well-informed implementation of OI. Better data are available for prizes than for other kinds of OI due to reporting requirements in the America COMPETES Act[6]. Even with requirements in place, however, there is known underreporting of prizes embedded in grants. A major obstacle to collecting and analyzing quantitative information, such as the investment in and effectiveness of OI approaches, is that OI is often one component of many in a larger project. Though this ability to combine approaches is a clear strength of OI, isolating the "OI effect" becomes difficult. Reliable measures will be essential for expanding and managing OI, as well as deciding when to use OI. We encourage the development of performance metrics, so project outcomes can begin to be tracked over time.

ii. Institutional barriers
Federal agencies are generally not set up to manage and use OI; their lack of infrastructure can manifest as any number of barriers. As a result, OI practitioners must frequently continue to entreat for institutional support. In instances where capacity has been built—including OI programs, trainings, and workshops; online toolkits; and communities of practice designed to improve and disseminate OI methods—the adoption and effectiveness of OI tools has grown rapidly (Gustetic et al. 2015). The annual report on Implementation of Federal Prize Authority [7] has tracked the policies and infrastructure that agencies have established since 2011 to support the use of incentive prizes. This report has helped disseminate insights about the institutional support needed to implement incentive prizes. Greater tracking and sharing of resources for all OI approaches will ease the use of these tools within a broader R&D strategy.

iii. Human barriers
The human challenges associated with integration of OI in an R&D program can be substantial. A three-year study of NASA scientists and engineers found OI approaches were either enthusiastically embraced or fiercely rejected, with virtually no middle ground (Lifshitz-Assaf 2016). Whether individuals belonged to the "embrace" or "reject" camp was strongly tied to perceived threats to NASA's identity as an R&D organization or to scientists' individual professional identities as expert problem-solvers. Similar struggles are playing out across the government (Mergel and Desouza 2013).

Top-down and bottom-up support is essential to the broader adoption of OI. Top-down support from senior agency leadership encourages program staff to apply OI approaches. Bottom-up participation spreads OI approaches more broadly and builds communities of practice. Communities of practice can help galvanize new strategies and directly increase the likelihood that projects will succeed (Wenger and Snyder 2000). Members typically include the project managers, staff, and agency scientists who are the "front-line" practitioners of OI. One example is the Federal Community of Practice for Crowdsourcing and Citizen Science, which connects practitioners from across agencies. Many agencies have also built internal communities focused on the application of OI to their specific missions.

Training and education are also key to the success of OI, but must be tailored to practitioner needs and to the ways in which they conceive of new approaches. To this end, we encourage periodic surveys of attitudes and requirements to help tailor training and education for an agency's broader workforce.

iv. More data are needed

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[6] See https://www.challenge.gov/toolkit/resources/ for previous reports on the Implementation of Federal Prize Authority containing data on quantity and use of the COMPETES prize authority to conduct Challenges.
[7] The Trump Administration's report is at https://www.whitehouse.gov/ostp/documents-and-reports/. Past Administrations' reports are at https://obamawhitehouse.archives.gov/administration/eop/ostp/nstc/docsreports.

As OI's integration into the federal R&D enterprise grows, government agencies need a clear framework for deciding what blend of R&D approaches can best deliver desired outcomes. In addition to policies and institutional capacity that enable OI, basic research will be vital for providing the scaffolding for this framework. Currently, NSF funds some studies that elucidate the basic social and technical processes underpinning citizen science and crowdsourcing approaches. Such studies build long-term R&D capacity in OI by exploring when, how, for whom, and for which types of research questions OI is appropriate and effective. Basic research about OI is currently happening on a project-by-project basis. Broad syntheses that can inform future policy and guidance frameworks are both increasingly necessary and increasingly possible as the field matures.

IV. Becoming an OI practitioner

To readers wanting to adopt OI methods into federal R&D, we offer the following suggestions:

1) Make room for risk. Create an innovation space on your team, in your program, or at your organization that expects and accepts a degree of failure and smart risk-taking.
2) Read about current practice. Although much research remains to be done, ample introductory material exists (see citizenscience.gov/toolkit).
3) Find a mentor or join a community of practice.
4) Pick a starting point. Examine problem spaces in which the current paradigm could be improved—these are fertile grounds for OI.
5) Prepare for change. OI challenges the norms of science and how R&D organizations operate. OI challenges the boundaries of what is possible and practical in R&D. And OI challenges assumptions about who is qualified to contribute to R&D.

IV. Conclusions

Open Innovation (OI) capitalizes on today's R&D ecosystem, in which knowledge and technology are widely distributed and cross-disciplinary collaboration is the new norm. OI by government is in a period of high growth, aided by recent policy changes and increasingly formalized infrastructure. We want to stress that OI is complementary to, and not a replacement for, the traditional R&D model. This article describes a range of OI approaches used by government, provides examples of applications, and illustrates how this agile set of methods is expanding the range of outcomes and accelerating federal R&D.

We encourage practitioners to contribute lessons and research to hasten the transition of OI approaches from experimentation to mainstream. Practitioners must collect better data and metrics for quantitatively evaluating impacts and outcomes, just as they do for traditional R&D. Reliable measures will be essential for deciding when and how to use OI, as well as for designing the management of OI programs. Science policy, economic, and social science research is needed to help identify when, how, for whom, and for which types of research questions OI is appropriate and effective in the federal R&D context. Research is also needed to identify how practitioners can systematically tailor blended approaches for greater effectiveness. We encourage institutional leaders to expand support. Greater tracking and sharing of experience and infrastructure at agencies for all OI approaches will facilitate the use of these approaches within the broader federal R&D strategy.

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