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It's the Partnership, Stupid

In 1990, the economist Nathan Rosenberg declared that "the linear model of innovation is dead." Unfortunately, the report of this death was, to paraphrase Mark Twain, an exaggeration. More than 25 years later, much research in universities, government, and industry is justified by invoking the linear view of innovation advocated by Vannevar Bush in his 1945 manifesto *Science: The Endless Frontier*. Bush argued for unfettered curiosity-driven basic research on problems chosen by individual researchers whose main goal was the pursuit of new knowledge. He believed that newly discovered knowledge would inevitably launch applied research projects, leading to commercial products that would be developed for appropriate markets.

Bush's linear model was simple and clear, but unfortunately rarely worked. Even Nobel prizes in physics often sprang from projects with practical orientation, such as the invention of the transistor to replace vacuum tubes that later led to the discovery of the transistor effect. Similarly, Arno Penzias and Robert Woodrow Wilson's practical work on improving microwave communications led to their Nobel Prize for finding the cosmic background radiation from the big bang.

Scholars of innovation and researchers alike have long realized that the linear model was flawed and that research successes often emerged from academic scientists working with practitioners on real problems. In his 1977 book, *Managing the Flow of Technology,* Thomas Allen, an organizational psychologist at the Massachusetts Institute of Technology, presented an evidence-based attack on the linear model that made it clear that research excellence often came from close collaborations with practitioners who faced real problems. Donald Stokes's influential 1997 book, *Pasteur's Quadrant*, celebrated Louis Pasteur's work on solving the problems of vintners whose fermentation processes failed or farmers whose milk went bad. Pasteur came up with the germ theory of disease as well as early attempts at vaccinations. A powerful lesson from Pasteur is that working on real-world problems jointly with practitioners often leads to the "twin-win": a validated theory that can be published and a tested solution that can be widely disseminated. Stokes has had some influence, but belief in the linear model remains strong, as do the academic incentives and rewards that reflect the model. Researchers who have benefitted from long-term funding for discovery-based research are well-established and have committed supporters in government and policy circles. As recently as March 2017, a hearing of the House Committee on Science, Space and Technology's Subcommittee on Research and Technology featured three leaders of the national research establishment who encouraged support for Vannevar Bush's model.

But this widely held belief about how to conduct research is being challenged by a growing community of scholars who are promoting a different set of research principles and are beginning to change attitudes at campuses, funding agencies, and businesses. Increasingly, collaborations between academics and practitioners focus on building teams that take a theory-driven approach to working on real-world problems. The best outcome from these teams is the twin-win of validated theories and practical solutions that quickly diffuse in society. Twin-win collaborations bring academics closer to real problems, so that when solutions are proposed they can be tested in real-world situations.

In the 2016 book *The New ABCs of Research*, Shneiderman (the first author of this article) outlines how scientific methods can be productively combined with engineering methods and design thinking to make discoveries and develop innovations. The book advocates "applied and basic combined" to "achieve breakthrough collaborations." In *Cycles of Invention and Discovery*, also published in 2016 (and reviewed by G. Pascal Zachary in this

issue), former Harvard engineering dean Venkatesh Narayanamurti and University of Virginia's Tolu Odumosu also rebel against Vannevar Bush, arguing that the artificial separation between applied and basic research is counterproductive. They dig deeply into the history of how the linear model became entrenched in policy circles and propose to reform academic policies and shift government funding. Taking this line even further, a group of information visualization researchers argues in a provocatively titled 2017 paper, "Apply or Die," that researchers must apply their work to real problems or risk becoming irrelevant.

These and other writings are productively challenging university leaders to change their research communities and reward structures. A common thread is the importance of incentives for academic scientists to work with business, government, and nongovernmental organizations to produce high-impact research that leads to influential publications while also helping to address the challenges of the day. National Medal of Science recipient Shirley Ann Jackson, president of Rensselaer Polytechnic Institute (RPI), calls for "The New Polytechnic." She encourages interdisciplinary work to attack the hard challenges of the world, while creating a new partnership model for interactions between the university and the world outside academia.

One productive form of campus interdisciplinary research brings together those with a problem to work with those who have an appropriate method for solving that problem. At the University of Maryland, for example, our work with off-campus partners such as the US Holocaust Memorial Museum, supported by a Department of Interior grant, led to the development of the highlighted link that is fundamental to World Wide Web usage. Another satisfying success was our work with a banking-machine manufacturer that led to the small touchscreen keyboards that are a key technology in smartphones. These collaborations led not only to the solution of real problems but to publications in top computer science and other disciplinary journals and conferences.

Guidelines for working with practitioners

Our experiences at the University of Maryland and RPI show that the key to the success of partnerships between academic researchers and practitioners with problems to be solved is to have well-considered plans that respect the goals of all participants. Of course, there are many principles of team formation, such as including an effective experienced leader and ensuring diversity in seniority, gender, disciplines, research methods, and personality. But making teamwork successful depends above all on partnerships built on four essential pillars of collaboration.

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Agree on project goals from the start. The key to successful projects is mutual understanding of what the goals are. When practitioner partners come to faculty members asking for help in solving well-understood problems that have little academic interest, university researchers have little motivation to collaborate. Conversely, when faculty members assert that their research will help solve some problem or other without working with practitioners to define the problem, there is little hope for success. Project goals must serve both practitioners' needs, such as developing or improving a product or service, and academics' aspirations to achieve advances in breakthrough theories that can be published in refereed journals and presented at conferences.

Of course, goals can change, but starting out with a written set of goals to be achieved within specific time frames helps keep everyone moving in the right direction. As the team forms, discussions to achieve consensus on the goals helps build team spirit, enables senior and junior members to exchange ideas, and allows everyone involved to learn about differing work styles within the team.

Discuss budgets, schedules, and data sharing. Long-term objectives such as "grand challenges," road maps, or the UN Sustainability Development Goals are admirable guides for broad programmatic

priorities, but successful individual projects need short-term goals so that tasks can be assigned to individuals and coordinated schedules can be established. Discussion of goals and tasks, with resolution of differences, also builds trust among team members. Resource allocation decisions provide the opportunity to clarify who needs equipment, staff, and funds. These discussions can be tense, but skillful leaders know that resolving such issues early promotes success. Another difficult issue can be data sharing, since corporations may want to protect data for competitive advantage and government data can have privacy restrictions. The University Industry Demonstration Partnership has developed a detailed set of principles and recommendations for data use agreements that cover issues such as who supplies the data, who is responsible for curating it, how long it will be kept, who will be able to access it, and how it will be archived or disposed of at the completion of the partnership.

Resolve intellectual property ownership and credit for outcomes. Since disagreements about intellectual property ownership, credit for outcomes, patenting, and publication can be contentious, early discussions and careful documentation are helpful processes. As collaborations are being formed, identifying each partner's background intellectual property helps set the stage. Then agreements about who will pursue and own patents or copyrights clarify responsibilities. Since academics are eager to publish and present results, a clear timetable for review and submission of papers ensures that all parties have a common understanding.

Develop partnerships at the technical and managerial levels. For large projects, success depends on having technical and managerial team members who work together to bridge their cultural differences. As an example, the recently announced Center on Health Empowerment by Analytics, Learning, and Semantics—we call it HEALS—is a multiyear partnership between IBM and RPI that includes coordination across many levels. The center has technical members who cooperate on specific projects, technical leads from IBM and RPI who oversee operations, a steering committee at the level of vice-presidents at each organization that reviews projects on a regular basis, and an executive committee that will perform a yearly review of the center's progress. The advantage of these layers of interaction is that they guarantee that as corporate priorities change in response to new business needs or as academic personnel change over this long-term partnership, the overall center is able to maintain continuity in pursuing the joint research interests.

Developing successful partnerships is hard work, but it can produce historic breakthroughs. A wonderful example is the effort by Rita Colwell, a former National Science Foundation director and National Medal of Science winner, to reduce cholera following monsoon floods in Bangladesh. In the late 1990s, she assembled a team of scientists and public-health workers in Bangladesh that developed a simple filtration strategy using women's cotton saris that could trap the plankton carrying thousands of cholera bacteria. Local public health-workers trained the women in 65 villages with 133,000 people on how to do water filtration. They collected mortality data from hospitals, showing a dramatic 48% reduction in cholera deaths. In the next decade, this astonishing twin-win result led to strong papers in leading journals presenting valuable knowledge about how epidemics spread, how they can be limited, and how the simple filtration methods can be sustained.

The culture is changing

Even when academic researchers make warm partnerships with practitioners, they must still deal with academic review committees for hiring, promotion, and tenure that too often focus on individual performance and theoretical contributions within a single discipline. In addition, funding agency review panels and journal or conference peer reviewers typically contain members who admire narrowly defined theoretical projects over larger applied efforts.

The good news is that a growing number of campuses are changing their culture. There are growing pressures for academics to justify their funding in terms of their impact on industry, education, and public policy. The twin-win here is that there is good reason to believe that the pressure of producing impact leads to significant theoretical results. To promote these types of synergies, the University of Southern California revised its tenure

policies to recognize collaborations and Duke University offers faculty contracts that stipulate the kind of interdisciplinary work tenure-seeking faculty plan to do. Another example of change is that more than 45 campuses in North America now treat patents as having equal value to published papers. A related movement at many campuses is to seek engagement with local, state, or regional organizations to promote economic development. The University of California's Center for Information Technology Research in the Interest of Society funds researchers at four campuses to conduct advanced projects that benefit the state. Working under the inspiration and discipline provided by real-world problems can inspire more creative thinking—and more realistic solutions. In fact, as many federal agencies are now opening "innovation centers" in Silicon Valley to understand how to make government projects more agile, scholars who have analyzed the success of the research process at Google conclude that research must go hand-in-hand with development to create real innovation.

Finally, especially with increasing pressure from Congress for research that can serve the national interest, funding agencies are figuring out how to break out of their traditional domain-oriented silos to encourage work that is highly collaborative and to reward projects that have the potential to transition to practice. Although there has been a long history of large centers awarding grants that incentivize or require interaction between researchers and industry—for example, from the National Science Foundation's Engineering Research Centers, the Department of Homeland's Security Centers of Excellence, and the Department of Energy's Innovation Hubs—this ethos has not generally trickled down to the smaller grants that support most researchers in the United States and many other countries.

This attitude is starting to change. National organizations such as the Government-University-Industry Research Roundtable of the National Academies of Science, Engineering, and Medicine, and the Association for Public and Land-grant Universities, are supporting ongoing efforts to spread the word about twin-win strategies, and funding agencies are beginning to embrace such strategies at the project level. For example, the National Science Foundation's Algorithms in the Field program "encourages closer collaboration between two groups of researchers: (i) theoretical computer science researchers, who focus on the design and analysis of provably efficient and provably accurate algorithms for various computational models; and (ii) applied researchers including a combination of systems and domain experts." Other programs in such fields as cybersecurity, data science, and resilient infrastructure also encourage collaborations and problem-centric research. We applaud these experimental programs and encourage more of this kind of thinking to further collapse the artificial and inhibiting boundaries between theoretical and applied research. They represent a gradual shift in research funding priorities that can have the effect of accelerating the advance of fundamental knowledge and real-world problem solving.

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When academics partner with practitioners from government, industry, and nongovernmental organizations, new opportunities are created to define problems that have interest to academics and value to practitioners. This mutually beneficial situation can lead to the twin-win: theoretical advances and published papers in peer-reviewed journals, as well as widely disseminated solutions that bring value to society. The linear model is dead! Long live the twin-win!

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