PASTEUR'S QUADRANT AND THE EDUCATION OF AN APPLIED GEOGRAPHER

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Early in my career, I was uncomfortable with the term "applied geography," first because my dissertation work had little practical use and later because I had difficulty separating my activities in knowledge production with their use-inspired, applied aspects. Several years ago, I came upon a 1997 book, *Pasteur's Quadrant*, which helped me to reconcile my joint interests in basic and applied research, and develop a new vision of myself as an applied geographer (Stokes 1997). The author, Donald Stokes, then Dean of the Woodrow Wilson School of Public and International Affairs at Princeton University, argued against the traditional continuum between pure and applied research and made the case for work that involves both knowledge production and application, using Louis Pasteur's research in the field of microbiology as an example. This book articulated an intellectual position for applied geography at the interface of science and policy with both pure and applied dimensions. I came to see applied geography as an essential component, rather than a derivative of the discovery of new knowledge. This view informs my current position as co-director of the Decision Center for a Desert City (DCDC), a National Science Foundation center focused on how to make better water management decisions in the face of climatic uncertainty.

I will use this essay to describe the evolution of my vision of applied geography, dating from my early experiences as a graduate student at Ohio State to policy work with the Morrison Institute for Public Policy at Arizona State University. I will demonstrate the relevance of *Pasteur's Quadrant* to that vision, and outline lessons learned as I struggle to link knowledge production with problem solving in my current position, focusing specifically on issues of identity (where do we fit on the map of science?), expectations (what do the consumers of our knowledge want from us?), and advocacy (does involvement in real-world issues compromise our status as neutral scientists?).

There is little in my educational background that would have led me to the world of applied geography. I attended Ohio State for my masters and doctorate in the early 1970s, and while the program contained some of the smartest and most creative geographers on the planet, they paid little attention to application. We talked about the grand theories of urban geography and regional development, but never once left the halls of the OSU Geography Department to witness the gentrification of inner city Columbus or the operation of rural development programs in Appalachian Ohio. We were oblivious to the great urban policy debates of the time, and consumed with nonlinear regression, simultaneous equation models, and spatial autocorrelation. Battelle Memorial Institute in Columbus hired me for part-time work, but I saw the applied projects that I worked on as intellectually distinct from my research interests as a graduate student. I positioned myself early for an academic position, and saw my work at Battelle as a vehicle to augment my meager graduate student salary and as a way to justify to my mom and dad that geographers did something useful.

After I arrived at Arizona State University in Tempe in 1975, I began to see my new home of Phoenix as an exciting laboratory for the urban, economic, and population processes that engaged me as a geographic teacher and scholar. My first introduction to policy work came in the early 1980s working with the Morrison Institute for Public Policy, an on-campus think tank involved in local policy debates about education, economic development, urban growth, inner city revitalization, open space preservation, and quality of life. I was invited to participate in a range of interdisciplinary research studies, and always found a way to "spatialize" the topics at hand, from the commuting problems of amenity towns in northern Arizona to the mismatch between jobs and housing in Phoenix's urban villages, elderly migration and retirement communities, immigration and inner city revitalization, and Latino labor force problems. I began to realize that the theories of urban, economic, and population geography had enormous utility in predicting and explaining the consequences of local and regional policy decisions. Although my Morrison Institute sponsors expected research results in the form of white papers, I established a decision rule for myself: if I could not translate the research product into a refereed journal article, I did not accept the project. I learned to frame relevant policy questions in a way that satisfied both my practitioner sponsors and my academic peers, and was regarded as the model academic—capable of meeting deadlines, finding the intellectual niche between knowledge production and policy analysis, and learning to write in plain English, instead of academic jargon.

While I found a viable niche as a geographer at the junction of science and policy, I gave little thought to the larger societal or scientific context for my work until I served as President of the Association of American Geographers (AAG) in 1997-98. In preparing my presidential address, I began to think seriously about the role of geography in society. How do we train graduate students, and how do we move from our current status as a small, academic discipline to one that plays a more prominent role in societal debates about climate change, sustainable development, urban growth, health, social and environmental justice, and poverty and inequality (Gober, 2000)? I read Vannevar Bush's 1945 report to the President, *Science: The Endless Frontier*, which laid the foundation for postwar science policy and justified creation of the National Science Foundation (Bush, 1946). As the former director of the Office of Science Research and Development during World War II, Bush made the case for the importance of basic research as an engine for technological and economic development. His linear model of science and society held that the social benefits of science often appear many years after the discovery itself, and sometimes did not appear at all. I believe that the discipline of geography has, in the main, bought into Bush's continuum between basic knowledge production and the application of that knowledge for real-world decision-making. Applied geographers use the ideas and methods of basic science for real-world problem solving, but the relationship is unidirectional.

While geographers cling to this view of science and society, many in the science and technology policy community have questioned Bush's linear model of knowledge, production, and application (Byerly & Pielke, 1995; Pielke, 1997; and Pielke & Byerly, 1998). Stokes' book, *Pasteur's Quadrant*, in particular, provided a cogent alternative, arguing that scientific activity is organized into quadrants (Figure 1). The upper left quadrant contains pure base research with little emphasis on potential use. Niels Bohr's work on the atom fits here. Thomas Edison, who conducted applied research specifically as a means to market electrical lighting, fits within the lower right quadrant. The lower left contains work that is neither theoretical nor applied, such as classification that is worthwhile but not driven either by the desire to advance knowledge or to develop practical solutions. The fourth quadrant contains use-inspired basic science such as the microbiology work of Louis Pasteur, and it contains work that has real-world utility, whose investigators never lose sight of the desire to advance scientific understanding.

Pasteur's Quadrant, at last, rang true to me and gave credence to my longstanding discomfort with the traditional "applied geography" label and my own efforts to link new knowledge production with the policy analyses

Research is inspired by:		Considerations of use?	
		No	**Yes**
Quest for fundamental understanding?	**Yes**	Pure basic research (Bohr)	Use-inspired research (Pasteur)
	No		Pure applied research (Edison)

Figure 1: Pasteur's Quadrant as adapted from Stokes (1997)

that I produced for the Morrison Institute. When I published my policy work for the Morrison Institute in formal journals, I implicitly recognized the recursive nature of science and policy—the applied work generated new ideas in addition to being a byproduct of those ideas.

My quest to work at the boundary of science and policy led me in 2003 to apply to the National Science Foundation's (NSF) Decision Making Under Uncertainty Initiative. This initiative was an attempt to reframe the climate change debate from the question of whether or not climate change has occurred, to how can we make better societal decisions in the face of inevitable uncertainty about climate. I teamed with an interdisciplinary group of scientists to study water resource decision-making in the face of climate variability and change in the rapidly urbanizing desert of central Arizona. Our project, DCDC, aims to produce the knowledge and develop decision support tools to foster better decision making in the face of climate uncertainty and rapid population growth. DCDC sits squarely in Pasteur's Quadrant and involves scientists and water stakeholders in its work.

In my role as DCDC co-director, I have learned a great deal about so-called boundary science from an evolving literature in science and technology policy. Kinzig, Starrett, Bolin, Dasgupta, Ehrlich, Floke, Hannerman, Jansson, Jansson, Kautsky, Levin, Lubchenco, Maler, Pacala, Schneider, Siniscalo, & Walker, (2004) articulated fundamental differences in the way science and policy communities perceive and deal with risk and uncertainty.

The scientific process involves advancing knowledge, and the costs of incorrect knowledge are high. Scientists use high evidentiary standards and accept only a small probability that their conclusions will be in err. Policymaking builds on the goal of addressing societal problems. Timeliness is important, and consequently, decisions often are made with an incomplete understanding of the problem at hand. We encountered this recently in an investigation of trends in snow pack on our watersheds during the past 25 years. Scientists are understandably reluctant to draw conclusions based on short-term records, but a crucial window of opportunity for water management decision making will pass if we wait for another 25 or 50 years of data to determine whether the anthropogenic climate change or natural climate variability causes the observed decline.

Kinzig et al. (2004) argue that four difficulties arise from the different perspectives of science and policy: first, a failure to appreciate the fundamentally different context in which science and policy function—the cast of characters, their reward systems, and methods of evaluation. Second, scientists sometimes do not address the problems that policy makers and decision makers perceive to be important because they shy away from complex, inherently uncertain socio-environmental systems in favor of more reductionist approaches where results meet strict evidentiary standards. Third, scientists may find it difficult to quantify uncertainty and therefore avoid such discussions altogether. Fourth, the neutral language of evidentiary standards can sometimes mask a debate that is at its heart, about values. Scientists advocate certain policies claiming scientific objectivity when, in fact, their positions derive from their own values, and policy makers invoke scientific uncertainty as justification for inaction on certain issues: witness the use of climate science to justify inaction on global-change policy (Pielke & Sarewitz, 2002-2003).

Cash, Clark, Alcock, Dickson, Eckley, Guston, Jager, & Mitchell, (2003) argue that efforts to use science to support policy are more likely to be effective when they manage the boundary between science and policy in ways that balance credibility (the adequacy of technical advances and scientific arguments), salience (the relevance of the assessment to the needs of decision makers), and legitimacy (the perception that scientific and technological experts have been unbiased, respectful of stakeholders' divergent values and beliefs, and fair in their treatment of opposing views). These standards have direct relevance to applied geography if you believe, as I do, that application involves a recursive relationship between those who are developing new knowledge and those who are using that knowledge for societal decision making. The applied geographer of the 21st century will mediate the boundary between geography and decision-making, ensuring that the discipline asks the questions that society wants answered and delivering the discipline's new ideas to decision makers in an understandable form. This is not a one-time job, but the result of a complicated give-and-take process, requiring trust, diplomacy, and perseverance. These skills were not taught to me in a graduate course or workshop, but were instead learned through on-the-job training and independent reading outside of geography.

I have found the murky world of boundary science to be rewarding but challenging. At the core of our work at DCDC is the ongoing, iterative process of developing a systems dynamics model linking water, climate, and urban growth. We have shown the first version of the model to local stakeholders, and have used their feedback to create "what if" scenarios of the future under different climate change scenarios, technological conditions, public values about water conservation, and urban planning strategies. Extensive interaction with stakeholders has revealed three challenges, and I believe all three are relevant to the larger world of boundary science and Pasteur's Quadrant.

First is the issue of identity. An effective boundary object or decision support tool allows geographers and decision makers to maintain their identities and distinct expertise. In our case, stakeholders are representatives from federal, state, and local water management agencies. Unfortunately, they hew to Vannevar Bush's conception of science and society as a linear process, and believe, therefore, that the water model belongs on the science side and has nothing to do with them. Their identity, and indeed their jobs, derives from expert knowledge of the rules that govern water management, the assumptions that underlie these roles, and the metrics that determine whether the rules are achieving their end goals. Scientists know less about these rules, data, and assumptions, but are experts in the physical systems that deliver water to central Arizona, the process of urban growth, and the social rules that govern decision making. Both stakeholders and scientists devalue each other's views because they know less about certain aspects of the model than the other group. There is very little recognition that the model represents the collective wisdom of scientists and decision makers with each group contributing what it knows best.

The second challenge is that boundary science leaves us open to unrealistic expectations. Community partners want to see consulting work; the NSF wants to see articles in *Science.* Consumers of our work have differing views of the metrics of success based upon where they see themselves on the linear model of science. I have made an uneasy peace with the fact that our work in Pasteur's Quadrant has different metrics and will probably meet nobody's standards of success. This is one of the great challenges of applied geography—to tell people what they did not expect or want to hear.

Related to that is the third issue of advocacy. Mixing knowledge production and real-world problem solving brings us dangerously close to accusations of advocacy and to criticism of the established order. Growth is the third rail of Arizona politics, and raising issues of water and growth can jeopardize relationships with key stakeholders. I had one valued stakeholder tell me that her organization would be unwilling to share data with us if our project said anything controversial about growth. Real-world problem solving threatens the position of scientific neutrality held dearly by many scientists.

I see myself today as an applied geographer, although I see the field as far more complicated than simply the application of new geographical ideas. Although I received no formal training in this area, it seems a natural fit for a geographer with curiosity about the world and an eagerness to make a small difference in that world. While I have found most of my ideas about the relationship between science and society, and basic and applied research outside the field of geography, these ideas offer powerful insight into applied geography's emerging role in boundary science.

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