Why CSCW Needs Science Policy (and Vice Versa)

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ABSTRACT

This paper explores the relationship between CSCW studies of scientific collaboration and the larger worlds of science practice and policy they are embedded in. We argue that CSCW has much to learn from debates in science policy, including questions around the changing nature of science and science-society relations that are partly but obliquely referenced in technology- or data-centered accounts of scientific change. At the same time, science policy has much to learn from CSCW – about design, infrastructure, and the organizational complexities of distributed collaborative practice. We conclude with recommendations for a better integration of the CSCW and science policy literatures around collaboration and new infrastructure development in the sciences, and speculation around what a post-normal cyberinfrastructure – and post-normal CSCW – might look like.

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science; collaboration; policy; collaborative tools; cyberinfrastructure; e-research

ACM Classification Keywords
A.m. Miscellaneous.

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Human Factors.

I. INTRODUCTION

Can CSCW research shape science policy? Should it? In her Athena Lecture at the 2012 CSCW Conference, Judy Olson challenged the field to think in new and creative ways about how and where the insights of CSCW might be brought to bear on real-world practices and problems. As Olson describes, the impacts of thirty-odd years of work in CSCW are in many ways impressive. The field has generated theory and findings that have changed the way researchers across several fields have approached questions of computational development and social change: HCI, computer, and information science, but also (albeit more modestly) psychology, sociology, organizational science, and science and technology studies. CSCW has shaped the education of large numbers of students at the doctoral, professional Masters, and undergraduate levels, many of whom have gone on to positions in research or industry that draw heavily on CSCW concepts and methods. Academic and industry-based CSCW researchers have helped shape the design and deployment of products and services at IT firms ranging from Microsoft, IBM, and Intel to Google and Facebook. And leading CSCW researchers have authored or contributed to key documents [8, 24, 36] that have been read and acted on by decision makers, managers, and participants in new collaborative projects in industry, academia, and the non-profit world.

At the same time, argues Olson, CSCW has not done all it might to achieve or extend impact, especially in light of the activist or social change leanings that led many participants to the field in the first place. CSCW has not yet done enough to translate its theoretical knowledge into forms and instruments (assessment tools, templates, toolkits, etc.) usable by the wider communities who might act on its findings. While the field has sometimes engaged in forms of action research with clear and measurable impacts on specific communities and areas of concern (e.g. [21, 30]), in other cases it has failed to engage communities in a sustained and meaningful way. And while individual researchers have made contributions to science and technology policy debates, the field's efforts in this space have been more limited than in the traditional CSCW heartlands of design; compare for example the near canonical status of 'implications for design' [11] versus the general neglect of 'implications for policy' in CSCW discussion sections. In all these ways, much work remains to be done to realize and extend the field's long-standing ambitions of impact.

This paper addresses the problem of CSCW impact in a contemporary policy debate of considerable importance: namely, the funding and development of new collaborative infrastructures in the sciences (the crux of today's cyberinfrastructure or e-research development efforts). It argues that while CSCW work has made important contributions along several key dimensions [8, 9, 17, 32, 37, 39] it has often struggled to connect its work to scholarship and practice in the wider science policy world. This is important for at least two reasons: first, because science policy is increasingly built and predicated

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(sometimes naively) around questions of collaboration and infrastructure that CSCW research has legitimate expertise in answering; second, because many of the challenges confronting CSCW researchers around scientific collaboration in fact flow from dynamics that live at the policy level – about which CSCW, in turn, may be naive. Better understanding of these dynamics can help CSCW to do its traditional work better, and move towards new sites of analysis and intervention that can expand the range and impact of the field.

This paper represents one theoretical and empirical step in that direction. Building on U.S. examples, it draws out CSCW contributions to science and cyberinfrastructure policy debates to date, and points to additional questions on which CSCW research has remained largely silent (or failed to connect to parallel debates going on in science policy research and practice). It draws in key frameworks from the science policy world – notably concepts of 'post-normal,' 'mode-2' and 'Pasteur's Quadrant' science – that can help explain the shaping, dynamics, and limits of contemporary cyberinfrastructure or e-research development efforts. It outlines ways in which CSCW-level discourses and practices nevertheless can and should feed back into more general science policy debate and analysis. Drawing on original ethnographic research into policy processes surrounding key infrastructure projects in ecology and water science, it speculates on the distinctive challenges attending the development of infrastructure under post-normal or mode-2 conditions. And it concludes by asking what this might mean for CSCW itself, as a collaborative, contextualized, and even post-normal endeavor.

II. WHY CSCW NEEDS SCIENCE POLICY

II.I. CSCW and scientific collaboration

For CSCW researchers, the study of scientific collaboration has always carried distinct intellectual and institutional advantages. Scientific researchers occupy a partially shared world with academic CSCW scholars, building useful forms of connection and understanding (common service on university committees, overlapping social networks, parallel work rhythms and calendars, shared institutional concerns around teaching and advising, research funding, promotion and review, etc.). Research in (some) academic science may be comparatively free of concerns around commercial competition, trade secrets, intellectual property, or national security that can produce pressures towards secrecy or closure in other contexts. In many instances, academic scientists engaged in collaborative research projects lack dedicated managerial or IT support and experience, making the organizational and design insights of CSCW researchers of immediate practical interest and benefit. Relationships between CSCW researchers and formal cyberinfrastructure development projects have in some cases been actively brokered or encouraged by science funders, building powerful incentives towards access. And CSCW studies of scientific collaboration have been historically well funded in their own right, giving important local support and legitimacy to faculty and doctoral research in this space.

For all these reasons, scientific collaboration has long functioned as a crucial site for the development and testing of CSCW theories, methodologies and technologies. Work by Star & Ruhleder [41] in the 1990s on the WORM Community System led to the development of core CSCW theory around the characteristics and tensions of infrastructure and its function within distributed collaborative communities. Research on scientific collaboration has also fueled the development of more general CSCW theories around distributed work (see for example the contributions to Hinds and Kiesler [23]). The early conceptualization of the "collaboratory" as a "center without walls, in which the nation's researchers can perform their research without regard to geographical location" [46] was an important precursor to subsequent generations of CSCW work around virtual teams [9], infrastructure design [13], and groupware [36].

This work has been extended in recent years through growing investments in scientific cyberinfrastructure (or 'e-research') among government funders in the U.S., Europe, and elsewhere. In 2003, the NSF published its Blue Ribbon Panel report, "Revolutionizing Science and Engineering Through Cyberinfrastructure" (aka the 'Atkins Report') [1], describing a "new age" in science and engineering research "pushed by continuing progress in computing, information and communication technology, and pulled by the expanding complexity, scope, and scale of today's challenges." Coming initially out of the Computer and Information Science and Engineering (CISE) Directorate and a longer history of NSF reports and activities in this space,[1] the Atkins Report described the hardware, software, and organizational possibilities embedded in a new suite of scientific communication, computation, and storage tools. In 2007 this vision was updated and extended under the NSF's "Cyberinfrastructure Vision for 21st Century Discovery," emphasizing the development of high performance computing, data visualization and analysis tools, virtual organizations, and new modes of workforce training and development as key opportunities and drivers of scientific change [44]. The report also emphasizes the cultural nature of the envisioned change: for example, NSF Director Arden Bement's claim that "at the heart of the

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[1] In rough order, the Lax [31], Branscomb [35], and Hayes [21] reports in 1982, 1993, and 1995; the NSF supercomputer centers and Advanced Scientific Computing Program of the 1980s; and the National Partnership for Advanced Computational Infrastructure (NPACI), High-Performance Computing (HPC), and NSF 'collaboratory' initiatives of the 1990s.

cyberinfrastructure vision is the development of a cultural community" built around "distributed knowledge communities that collaborate and communicate across disciplines, distances, and cultures." [44] This broad vision drove the 2005 formation of the NSF Office of Cyberinfrastructure and a new suite of funding programs (though never the $1 billion the original Atkins Report called for) dedicated to the design, construction, and analysis of transformative cyberinfrastructure.[2] Many of these programs have become important sources of support for ongoing CSCW research in this space.

Activities at the NSF have been broadly paralleled by programs at other funding agencies in the U.S., Europe, and elsewhere. In 2000, the U.K. Director General of Research Councils from the Office of Science and Technology, coined the term "e-Science" to describe infrastructures supporting distributed and interdisciplinary collaborations. This was followed in 2001 by a report from De Roure et. al. [10] articulating a plan and agenda for the development of e-Science tools and infrastructure built around the principles of service-oriented architecture and the semantic grid. Other European initiatives soon followed, including the Netherlands e-Science Center, European Grid Infrastructure, the Danish e-Science Center in Copenhagen, and a range of activities sponsored under the Ministry of Science and Innovation (MSI) in Germany. In Asia similar initiatives have recently been launched, driven in part through collaborations and partnerships involving U.S. and European researchers and institutions – for example, the Academia Sinica Grid Centre (ASGC) in Taiwan associated with the European Enabling Grid in e-Science (EGEE).

Other important institutional actors, including many located at industrial research firms like Microsoft, have pursued questions of scientific transformation with a principal focus on data – and the potential that new and extended forms of data collection, storage, processing, and analysis can bring. Such advocates point to an emerging "4th paradigm" of science, in which tailored but interoperable algorithms, software, data analysis, and information management tools emerge to manage and accelerate forms of learning and collaboration built on the new torrents of data produced by increasingly massive systems of scientific instrumentation and monitoring. The same rough principle finds its dystopian counterpart in fears around the 'data deluge': namely, that our proliferation of data has become so intense that it overwhelms our ability to keep up and make sense of it at all. [12]

The explosion of activity and support in these areas has fed new generations of CSCW research. Lee et. al. [32] have explored "the human infrastructure of cyberinfrastructure," calling attention to human and organizational actors integral to the function of cyberinfrastructure that are often obscured in prevailing tool- or technology-centered accounts. Other researchers have emphasized temporal dimensions and challenges of infrastructure development in the sciences, examining tensions between short and long term orientations [28, 38], and the more general problem of aligning collaborative rhythms [25]. Other researchers have explored behavioral motivations towards collaboration and data sharing, emphasizing individual and institutional incentives that might support or undermine patterns of scientific sharing and collaboration [3, 4]. Others have sought to tie such patterns to systems of scientific credit and reward, including the crucial but fuzzy concept of authorship [2]. Still others have focused on thorny questions around data production [45], curation [28], ontologies [33], metadata [14], and reuse [16].

II.ii. Cyberinfrastructure and the policy gap

Many of the above questions relate to questions of science policy, at least in the loose sense of relating to problem areas (for example, data) that contemporary policymakers have sometimes sought and struggled to address. Other CSCW work has attempted to make this link more direct, pointing to features of the policy world that can impact local practices of collaboration.

The 2007 Understanding Infrastructure workshop and report [13, 24] explored tensions and dynamics surrounding the development of large-scale infrastructure, pointing to issues around sustaining funding, the differing practices of funding agencies across initiatives, and the influence of publishing on the research and development process. The report locates the development of cyberinfrastructure in a wider political economy shaped by the pairing and discrepancies of public and private sector interest, the shifting interests of funding agencies, the emergent properties of plan and planning, and the institutional norms and cultures that bear on the practice of scientific work in lab, field, and classroom. Some of these themes are taken up and extended in Ribes & Finholt [38], which locates cyberinfrastructure development and practice in a wider and multi-scalar frame, including a series of macro-level tensions that operate at the institutional level of funders like the NSF. Kee [29] makes a similar point, linking challenges and discrepancies in scientific collaboration to a series of "dialectical tensions" in the funding of cyberinfrastructure. Cummings and Kiesler's [9] analysis of NSF ITR grants from the 1990s has revealed the significant coordination costs imposed by the inter-institutional organization of academic research teams.

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[2] For example, interdirectorate programs in Human and Social Dynamics (HSD); Cyber-Enabled Discovery and Innovation (CDI); Virtual Organizations as Sociotechnical Systems (VOSS); and changes to a host of existing programs and mechanisms (including the MREFC instrument described below) that sought to realize and extend the NSF's cyberinfrastructure vision.

Other CSCW work has approached questions of policy through the medium of data. Work by Borgman [4] has explored the links and frequent discrepancies between the everyday data practices of scientists and the data sharing guidelines and mandates of institutional funders like the NSF, NIH, and European funding bodies (including key centers like the UK Wellcome Trust and Digital Curation Center). Vertesi and Dourish [45] have emphasized the political economy of data production, exploring the significance and diversity of local and institutional contexts of data production, and arguing against simplified and commodified visions of data economies and the one-size-fits-all approaches to regulation and policy they can produce. Howison & Herbsleb [22] have pursued broadly parallel questions around the provision, circulation and maintenance of software in the biology and physics communities, pointing to the interaction of funding structures, systems of academic credit and reward, and software licensing practices as constraints and shapers of collaborative practice in these worlds.

In all these ways, CSCW as a field has approached but not fully tackled the broader questions of science policy that frame and shape efforts at cyberinfrastructure and collaborative scientific development. Institutional and policy constraints have been acknowledged as an outer ring of CSCW concern, but rarely thematized as a topic of CSCW research per se. In their introduction to the special issue on cyberinfrastructure of the Journal of CSCW, Ribes & Lee [40] note the project-level and short-term inclinations of the field, and argue for a more holistic examination of cyberinfrastructure as "something sorely needed in the field" (pp. 240). Karasti et. al. [27, 28] applaud CSCW's insight into the short-term and design-sensitive analysis of distributed collective practice, but urge it to think longer and broader – a recommendation that includes attention to questions and phenomena like institutions, laws, and policies that live on a different scale. CSCW has in some instances become good at speaking back to the people who practice, manage, and build cyberinfrastructure, but the main practical import of its lessons tend to be posed and absorbed at the level of project management, such as best practice guides on how to build and support collaborative science projects under current operating conditions. It has rarely turned its attention to larger questions around the mechanisms and broad policy choices that set those conditions, or engaged in a deeper sense how policy-level shifts and dynamics can advance or retard, enable or undermine, the collaborative concerns, issues, and possibilities we care about. This is a world that CSCW researchers who care about scientific collaboration can and need to connect to. But to make this bridge, we need new ideas and approaches. Science policy can help.

III. CHANGING SCIENCE: THE VIEW FROM SCIENCE POLICY

In the immediate aftermath of World War II, the U.S. scientific establishment faced a question: what to do with the resources of the nation's science community recently mobilized by war? An early and influential answer was offered by Vannevar Bush, head of the Office of Scientific Research and Development (OSRD) that had overseen the unprecedented national organization and expansion of scientific research funding during the war. In his influential 1945 report *Science: The Endless Frontier* [6] delivered to President Truman and his more popular July 1945 Atlantic Magazine essay, "As We May Think," [7] Bush supplied a framework that would shape U.S. (and in smaller measure western European) science policy thinking and practice through most of the ensuing decades. At its core was a call for a National Research Foundation that would carry on some of the funding and leadership activities of the erstwhile OSRD, organized now under civilian auspices. The new foundation would continue the wartime pattern of public support for basic scientific research (arguably the most significant and enduring invention of the war), ensuring the continuity of the massive research explosion stimulated by conflict while directing these to new and peaceful ends (basic discovery, economic growth, etc.). In Bush's proposal, the new foundation was to be science-run and science-led, with minimal interference from Congress or indeed the broader public.[3]

In 1950, this vision was realized (with modification) by presidential advisor John Steelman in the form of the National Science Foundation Act [42]. At the core of the model was a central trade-off or compromise. Science would be supplied the kind of resources, discretion, and autonomy called for by Bush. In exchange, it was expected to deliver findings, insights, and eventually applications that would feed national economic growth and global competitiveness, quality of life, and improved public decisions around matters of common concern. Investments at the new NSF would be targeted towards "basic" research, whose findings were expected (but only later) to feed into downstream forms of application and products that would produce the payback on public investment. This basic trade-off came to be called America's "social contract with science."

At the heart of this vision lay a distinctly linear imagination of scientific research and impact, which was likened to a pipeline. Suitably primed, the pump of science would produce breakthroughs and discoveries that would flow through (more or less automatically) into applications, products, and other goods of clear public value. As a model of innovation, this represented a science-push stance that argued for the course of scientific discovery as best and

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[3] While space allows us to focus only on features of the U.S. model, some of these principles were replicated in different forms in the systems of postwar science funding emerging in Western Europe and later East Asia.

most reliably guided by the native curiosities and standards of scientists themselves. Efforts to tie programs of research to distinct social or national goals or subject them to popular or Congressional scrutiny were, beyond a certain very general point, regarded as unhelpful and more likely to dry up the pipeline than to focus or direct it in any successful way. From the standpoint of policymakers and the general public, science was to operate as a black and somewhat magical box: funding would go in, and some time later (through means radically underspecified in the model) useful results or products would come out. Above all, the whole process was to be driven, evaluated, and run by scientists [20].

This postwar "social contract" did important things for the organization of science. It established the standing of universities alongside industrial and government research labs as leading recipients of federal research dollars and sites for scientific research in general. It established key institutional principles and mechanisms, including the process and centrality of peer review, by which quality was to be assessed and resources allocated. It set up the unique system of NSF "rotators", in which practicing scientists would spend periods of time at the NSF in functional roles ranging from Program Officer to Assistant Director. In its directorate and program structures, it established divisions and fixed boundaries between what were then often still nascent disciplinary identities and divides (though made less nascent as the effects of institutionalization set in). It established, in fact, the principle of organizing the funding of American civilian science around disciplinary principles at all. (Imagine for example how different the world of science policy and infrastructure might look today had Bush and Steelman chosen to organize the civilian science effort around *problems* rather than 'fields.') Above all, it drew a bright red line down the center of the science/society relationship, and established the terms of exchange on each side: society, in the form of taxpayer dollars and cultural consent funneled through the NSF and similar bodies, would provide the dollars and an extraordinary degree of autonomy and generalized trust; science would pursue its work guided by its own internal lights, and eventually, as basic research filtered through to applied insights and products, supply the goods. These general principles constituted the starting point for how we would approach questions of science and science policy for the next half-century, and arguably still dominates the imagination – and in some quarters, the practice – of science policy today.

III.i. Post-normal science

While the postwar pipeline model was not without critics from day one, it took until the 1970s before alternative principles began to emerge in the science policy literature. An early and important example of this came in Funtowicz and Ravetz's [18] arguments around the changing nature and policy implications of "post-normal" science. As Funtowicz and Ravetz describe, the emergence and recognition of post-normal science rests on the growing realization that "the new problems facing our industrial civilization, although requiring scientific inputs for their resolution, involve a problem-solving activity that is different in character from the kind that we have previously taken for granted." Citing the increasing social salience of risk and the demonstrated failure of predictive risk assessment techniques, post-normal science emphasizes the experience and growing prominence of fields like nuclear and environmental regulation, where "facts are uncertain, values in dispute, stakes high, and decisions urgent." Under such conditions, the "puzzle-solving" orientation of normal science breaks down, and new forms and strategies may be required: "extended stakeholder dialogues," "extended peer review," and even "extended facts" built on inputs and participants (e.g. communities affected by environmental decision-making) beyond the usual scientific set. Such fields thus encounter and ultimately depend on a degree of epistemic pluralism unaccounted for under the pipeline model: both at the intersection of previously distinct and self-governing disciplines, and the more radical and sometimes fractious break between scientific and broader public means of assessing knowledge and risk around matters of common interest and concern.

Beyond the difficulties of adjudicating competing knowledge claims in regulatory and other decision contexts, post-normal science may have implications for the kinds of knowledge infrastructures we seek to build and support as a matter of policy. To begin, the increasingly blended quality of the problems that large-scale infrastructures are called upon to solve point to earlier and more complex disciplinary integrations at the level of research; the kinds of conflicts and disputes noted by Funtowicz and Ravetz as a feature of the regulatory arena are thereby pushed back into the infrastructure of the research process itself. The same blended and extended quality produces both arguments and a constituency for earlier and more substantive engagement with concerned but non-credentialed publics, seen for example in popular epidemiology [5] or patient group activism [15]. These groups, too, are being pushed back into the infrastructure in ways unanticipated and awkwardly accommodated under pipeline models of the research process.

III.ii: Mode-2 Science

Over the past 20 years, a loose collective of European science policy scholars [19, 34] have offered an alternative take on science policy reform. Like Funtowicz and Ravetz, their prescriptions follow from a fundamentally different take on the relation between science and society: not the separate, arms-length and linear relation imagined under the post-war social contract, but a more complex, intimate, and dynamic one in which society enters into the making and shaping of science, and vice versa, from day one. This relationship extends from the definition of problems of interest, to the public negotiation of scientific fact, to the entry of non-credentialed experts into the high-stakes game of scientific expertise and decision-making.

In all these ways, argue Nowotny et. al. [34], scientific knowledge finds itself increasingly "contextualized": whether the "weak" contextualization of CERN and the particle physics community (in which the autonomy of internal science decisions continues to weigh heavily against the social claims and rationales for investment); or the "strong" contextualization of contemporary environmental research programs (in which scientific autonomy and internal shaping may be outweighed by specific claims of social or public interest). In such a "mode-2" world, both the justification and autonomy of science have become less automatic than under the Endless Frontier ("mode-1") vision. Science retains enormous importance and cachet; indeed, its reach into the details of social life is arguably intensified and expanded. But it is also expected to provide a better and more specific account of its activities, and to operate within a more pluralistic universe of knowledge and values, in which it remains a crucial but no longer necessarily dominant player. These effects are strongest where mode-2 conditions of uncertainty, pluralism, and deep social values most apply.

In Nowotny et. al.'s wide-ranging discussion, mode-2 science is characterized by a number of additional traits: the increasing social distribution of expertise and broader appreciation for the values and contributions of more distributed knowledge forms; the heightened importance and permeability of key knowledge-making institutions, like industrial and government research labs, research councils, and universities; and a shift from certainty and reliability to "socially robust knowledge" as a value and marker of effective scientific work. These features have implications for the internal organization of research (a line which is indeed increasingly difficult to demarcate). Thus, pluralism is recreated and celebrated in the form of interdisciplinarity, as the disciplinary organization of "basic" research is replaced by a more "applied" focus on problems, around which disciplinary structures and interests are left to sort themselves out. Science funders are increasingly insistent on measures and rationales of impact; more stringent around questions of project management and reporting; more directive in channeling scientific work towards socially identified goals and objectives (e.g. the numerous "grand challenge" frameworks issued by national academies and federal funders in recent years); and insistent on the transformational quality of publicly-supported research. In these and other ways, mode-2 approaches look to balance the competing claims of scientific autonomy and social accountability in ways fundamentally different than under the postwar social contract.

III.iii. Pasteur's Quadrant

A leading example of post-pipeline approaches in U.S. science policy scholarship comes from Donald Stokes [43] and his emphasis on the importance of "use-inspired basic science" as a form and model of scientific research. Drawing on leading historical scientists as exemplars, Stokes divides the world of research into four basic quadrants defined by orientation towards the quest for fundamental understanding on one hand, and considerations of use on the other. These span the spectrum from forms of pure research conducted with no consideration for downstream use or impact (personified by physicist Niels Bohr's work on the atom), to the highly applied forms of research exemplified in Thomas Edison's invention of the phonograph. But Stokes' true interest lies in a third form that combines the best features of each: "use-inspired basic research" as exemplified in the work of Louis Pasteur.

Work in "Pasteur's Quadrant" exhibits features that mark it as a particularly promising target for public investment. It requires no faith in the magical efficacy of the pipeline, as considerations of use enter into the framing of research in its early stages. It fits well with the political realities of science funding, including popular expectations that scientific research will feed into matters of public concern in more direct ways. In training the efforts of the scientific community in particular directions, it may improve the strength and efficacy of the science-technology link, while providing constraints and scaffolding that in fact focus and inspire rather than restrict path-breaking forms of research. And it may provide a more accurate description of how research works in the world, while building deeper and more generative relations between forms and sites of work – for example, academic and industrial research labs – that tend to get separated and/or mystified under the basic/applied split central to Bush's model. In all these ways, work in Pasteur's Quadrant shows better hope of modifying, renewing and sustaining the social compact with science under the conditions of a globalizing and post-Cold War world.

III.iv. Discussion

Taken collectively, the post-normal, mode-2 and Pasteur's Quadrant frameworks provide a useful extension to the simplified assumptions of the post-war social contract ideal. As each of these models suggest, the basic relationship between science and society may be undergoing profound change, both politically and institutionally. It is not clear, as debates from stem cell research to climate change suggest, that scientific experts now or will ever again possess the kind of unassailable public respect and authority granted them under the postwar social contract. Nor is it clear that the dominant post-war mechanisms of science funding and evaluation championed by Bush – single or small-team PI-driven research awarded on a project basis and vetted through discipline-centered forms of peer review – are adequate to the increasingly mode-2 problems we encounter. Instead, we are likely to see interdisciplinary and translational mechanisms and mandates expand, along with new efforts to link academic research with sites and actors that would have once looked distinctly and suspiciously 'applied' – practitioners, commercializers, etc. Many of these challenges only intensify as we turn to the emergent, integrative, and fast-moving areas of science that cyberinfrastructure developers have targeted as particularly promising sites of impact and transformation. These conditions tend to magnify rather than reduce the types of uncertainties, collisions, and combinations noted above as features of a post-normal, mode-2 or Pasteur's Quadrant world.

All of these points are borne out when we turn to the forms of cyberinfrastructure development being pursued at the NSF and other funders today. Beyond the enabling role of tools and technologies, the shifting social conditions of science provide the single best explanation for why we need many of the things that cyberinfrastructure promises to deliver – collaboration, interdisciplinarity, larger and multiple perspectives on problems of public import, etc. In this regard, cyberinfrastructure is as much a child of science policy and shifts in science-society relations as it is of technology per se. But as the brief empirical vignette that follows illustrates, these same features pose distinct challenges to design, governance and practice that CSCW scholars need to take into account.

IV. EMPIRICAL DISCUSSION: POST-NORMAL TENSIONS IN THE DEVELOPMENT OF CYBERINFRASTRUCTURE[4]

In 1995, the National Science Foundation established its first agency-wide account for the regularized funding of major science and engineering infrastructure. Subsequently renamed the Major Research Equipment and Facilities Construction (MREFC) Account, the new category was designed to support the planning and construction of crucial large-scale infrastructure whose costs (typically in the hundreds of millions of dollars) exceeded and sometimes dwarfed the budget capacities of individual NSF directorates. Candidate projects were required to go through an intensive multi-year planning and review process modeled after project management techniques drawn from the defense sector and mission science agencies like NASA and the Department of Energy. The process proceeded through a series of structured steps culminating in National Science Board, Office of Management and Budget, and Congressional review.

In comparison to the PI-driven research programs dominating most other activities of the Foundation (often referred to as 'R&RA' activities, for 'Research and Related Accounts'), prospective MREFC projects are subject to an unusually detailed and complex set of demands. To pass muster with peer and internal NSF and National Science Board reviews, MREFC planners must articulate a basic research program around a unified set of science questions that meet the standards of traditional and usually discipline-based peer review. At the same time, NSF, White House and Congressional leaders – who ultimately approve or disapprove projects as annual line items in the Presidential and Congressional budgets – must be convinced of the broad public merit of the requested investment, usually by promoting the project's ability to provide new and crucial findings that help solve problems of identified national interest and need. This intense political engagement can erode the autonomy scientists have traditionally enjoyed, and departs from the insulated pipeline model characteristic of the post-war era. In many of the cases we've studied, it also sets up a series of difficult-to-resolve challenges and tensions that lie at the intersection of mode-1 and mode-2 expectations and concerns.

One MREFC project for which this clash proved problematic was the Water and Environmental Research Systems (WATERS) Network, a proposed $400 million effort to create a national network of observatories and cyberinfrastructure for water-related research in the U.S. that arose in the early 2000s and ended in most respects with the failure to secure ongoing MREFC support in 2010. In the broadest terms, the WATERS effort brought together three distinct groups: a consortium of hydrologic scientists intending to develop new infrastructure and support tools for hydrology; a parallel and initially separate group of environmental engineers seeking to develop similar infrastructure for environmental field facilities; and somewhat later teams of social science researchers working on questions of human and social consumption. The union between the first two groups was often characterized by our informants as a "shotgun marriage" necessitated by the fact that leaders at the NSF and in Congress were unlikely to fund two separate and expensive infrastructure projects in the broad water space.

Almost from day one, the WATERS effort faced major challenges in aligning the worldviews of its two (later three) constituent fields: as described to us, on one hand the

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[4] This section draws on ethnographic work conducted by the first and third authors between May 2009 and December 2010. During this period we conducted 26 semi-structured interviews with WATERS project leaders and participants, NSF officials, and members of the Congressional and White House science policy staffs. Each interview took 1-2 hours in length, and was transcribed and coded according to grounded theory principles. We also participated in several workshops dedicated to the planning and evaluation of WATERS and other large-scale science projects, and reviewed documents and reports coming out of the WATERS planning effort, official project reviews and meeting notes, workshop reports, technical reports associated with WATERS and related network initiatives, and several policy reports associated with the construction and funding of large-scale science infrastructure. Fuller analysis of the WATERS case appears in separate work currently under review.

curiosity-driven nature of hydrologic science, and on the other the problem-solving nature of engineering. The difficulty of this alignment showed up most clearly when it came time to articulate the science questions that would drive and justify the new network. As numerous informants and the members of the National Science Board that reviewed and ultimately panned the WATERS proposal recounted, the proposal lacked a compelling and unified set of concerns that would unite and justify the work from a ‘pure science’ point of view.

WATERS also faced challenges around the shifting composition and nature of NSF management and advocacy around the project. High turnover rates among NSF rotators from the program officer up to the Assistant Director levels led to shifting waves of interest and enthusiasm as key supporters and senses of priority came and went. Finally, the distinctly linear style of MREFC development produced endemic problems of currency and timeliness. Under the terms of the MREFC, the design of infrastructural components is to be blueprinted early in the process in an attempt to build accountability and freeze costs. This becomes problematic in areas where the infrastructure in question lacks the one-time capital equipment quality of an accelerator or telescope (the models after which the MREFC was originally imagined) and where technological advances tend to be rapid. A fixed design runs the risk of becoming obsolete by the time the technical infrastructure components are actually built and implemented, posing deep challenges to more incremental and adaptive development models. The extent to which the timeline was truly fixed – and indeed, what could count as infrastructure at all – was also subject to disagreement and evolution by the various actors involved, including the different directorate constituencies at NSF.

Issues like these raise questions around the crucial interaction between policy-level entities like funding categories and the forms of design and collaborative practice more commonly addressed in CSCW research. They also raise questions around whether emergent and collaborative research networks can be effectively built through the MREFC mechanism in fields not previously organized around large equipment investments (e.g. physics and astronomy), and whether the MREFC mechanism itself may need to be rethought or applied differently for problem areas that draw in fields and research communities traditionally organized along decentralized and small science lines. Here again, CSCW expertise around infrastructure, coordination, and collaborative practice may have central contributions to make.

There are however important counter-examples to the WATERS experience. Running through the MREFC milestones just ahead of the WATERS planning effort was the National Ecological Observatory Network (NEON), a distributed and national scale ecological research platform that ultimately overcame the problems and controversies that scuttled the WATERS initiative and in summer 2011 officially moved into construction. On the face of it, NEON bears certain resemblances to WATERS. Like WATERS, it sought to organize a community of work with a fairly limited prior history of centralization, big infrastructure, or large-scale collaboration. Like WATERS, it faced the challenge of matching an expansive and distributed suite of infrastructure investment against the need for a coherent but potentially evolving set of science questions. And like WATERS, it was required to satisfy internal criteria of scientific legitimacy and review while making a compelling case for impact and national priority at the policy and wider public levels. At the same time, as informants at both WATERS and NEON noted, there were important features that set the two networks apart. First, through most of its planning history NEON retained high-level champions within the NSF whose support was maintained and transferred through successive rounds of rotation and turnover. Second, whereas WATERS was a multidisciplinary and multi-directorate effort (spread between the Biological Sciences, Engineering, and Social Behavioral and Economic Sciences respectively), NEON came out of a single directorate (Biological Sciences) and was thus spared some of the larger institutional and disciplinary translation problems that afflicted the WATERS effort.

As the extremely truncated stories of the MREFC, WATERS, and NEON begin to suggest, efforts to develop collaborative infrastructure in the sciences are likely to confront significant barriers and challenges at the policy level, many of which live in the tension between a mode-1 and mode-2 world. We have seen, for example, how projects such as WATERS can get caught in the middle between problem and discipline-centered framings and expectations of infrastructure, and how this plays out in the uncertain politics of peer and wider Congressional and administrative review. Normal versus post-normal orientations may also work their way into the complicated politics of scale and rhythm that attend the development of new collaborative infrastructures in the sciences. There is debate, for example, around the relative merits of centralist vs. distributed funding models, the big push vs. the long tail (or what we’ve identified elsewhere as the question of Networks vs. networks). The former lives easily in a mode-1 world (recall that the orienting metaphor for large-scale infrastructure projects under the MREFC remains the ships and telescopes of established research communities), and has many of the virtues that scale and stability bring. The latter is less certain, and doesn't look necessarily like *either* the large capital projects traditionally funded as infrastructure at the NSF or the short term and one-off tradition of the investigator-led project. The same general discrepancy may attend key questions around time and rhythm that shape the development and practice of collaborative infrastructure in the sciences [25].

Finally, transitions and legacies between earlier and contemporary moments of science policy may be reflected in the somewhat complicated institutional dynamics and limitations that surround the efforts of agencies like the NSF. In many key respects, the NSF today looks different than the agency founded in 1950. The work the foundation supports, the problems it seeks to address, its mechanisms for intra-agency brokering and coordination, and the relations it maintains to government and the broader public have all shifted, in lesser and greater ways. But in other key structural and perhaps cultural regards, the institution looks uncannily the same. With minor adjustments for content and certain efforts at foundation-wide integration, the NSF's basic structure and operation remain unchanged from its early post-war manifestations. The agency still follows the same basic principles around peer review, rotation, and evaluation championed in The Endless Frontier. If the ghost of Vannevar Bush were to return to the NSF today, he would almost certainly find the place recognizable. But this raises deep questions about the relationship between institutional stasis and the kinds of flexibility and innovation better associated with creative and forward-looking work in the science policy space. In the language offered here, the NSF circa 2012 may be a normal institution trying to do post-normal things. Nowhere are these tensions more evident than in the complex and emergent world of new infrastructure development and collaboration in the sciences.

VI. CONCLUSION: WHY SCIENCE POLICY NEEDS CSCW

We have now discussed possibilities and challenges confronting the development of collaborative scientific infrastructure in the distinctly post-pipeline world of contemporary science policy. As the discussions of MREFC funding and the more specific challenges of projects like WATERS and NEON make clear, collaborative science efforts today must navigate a more complex policy world than the one described and partially built by Vannevar Bush. Contemporary collaborative science projects like WATERS, NEON, and other efforts studied by CSCW researchers are both children and victims of this new environment. The trends toward contextualized, problem-centered and translational research account for many of their most distinctive features, and in fact help explain the more interdisciplinary and collaborative models of work at their core. But they also present projects like WATERS and NEON with some of their thorniest problems: challenges of interdisciplinarity, conflicts between scientific autonomy and social responsiveness, etc. Many of these tensions and uncertainties stem from the messy intersection of mode-1 and mode-2 expectations and realities. It is this intersection, rather than the neat description of either, that defines the making and doing of large-scale collaborative science today.

In such a world, it turns out, science policy has much to learn from CSCW. The first and most obvious contribution concerns design and the role of tools and infrastructure as avenues or drivers of change. It is striking, for example, that neither the post-normal, mode-2, nor Pasteur's Quadrant frameworks pay much attention to computational development as a source of change in their models (a rather shocking absence, given the dynamism of changes in this sector. If fourth paradigm and other data or tool-centric accounts make too much of computing as a driver of scientific change, the broader science policy literature almost certainly makes too little. In failing to engage design in a specific sense, science policy loses the chance to draw more specific lessons: for example, the rather important one of how different modes and approaches to infrastructure development might impact the world of science and broader science-society relations differently. Science policy frameworks have tended to emphasize sociological or natural drivers of change to the general neglect of the crucial relationship between tools and everyday practices of work – something CSCW has a great deal to say about.

Second, CSCW research has much to say about the human and organizational dimensions of distributed collaborative forms. Where science policy struggles to understand the effects of individual users and the ties and forms of exchange that bind them into more and less loosely bound collaborations, CSCW has developed rich theoretical and methodological traditions around these questions that science policy has for the most part failed to grasp.

Third and finally, common CSCW approaches and sensibilities around the iterative nature of planning and development might help change the way we think about the relationship between planning and practice in the science and wider policy communities. As evidenced in the above discussion of the MREFC planning process, science policy mechanisms and debates may be uncomfortably stuck in a view of the world that unreasonably divorces planning from downstream action, undermining necessary principles of flexibility, adaptation, and the opportunities for learning and correction they provide. CSCW design approaches built around different principles – iteration, interactivity, prototyping, etc. – may have important contributions to make in opening up this world. For these and many other reasons, science policy needs CSCW.

Ironically, such an engagement may raise distinctly mode-2 questions for CSCW itself. Can CSCW think towards new modes and aspirations for engagement, above and beyond its usual forms and sites of work (and can the insights of scholars like Nowotny, Funtcowicz and Ravetz, and Stokes help get us there)? What might such a move do to our own 'internal' practices of knowledge making (and how should we respond)? Is there such a thing as post-normal CSCW? And should there be?

The question as framed is misleading. In many key regards, CSCW was born post-normal, an example (even a poster-child!) of the sorts of disciplinary mixing and science/society reconfigurations that post-normal and mode-2 scholars have emphasized. The concerns around impact that opened this paper, for example, are recognizably mode-2 concerns and would be largely foreign to the researchers of a pipeline world (in which impact is taken as a matter of faith, or as someone else's business.)

But as illustrated above, the conditions and tensions associated with post-normalism, Pasteur's Quadrant, etc. also pose distinct difficulties and challenges, some of which we would expect to see in the form of tensions and divisions within the CSCW community. These map in predictable ways the ones noted above: for example, tensions around evaluation (how to judge quality across methodological and disciplinary divides?); credit (how to weigh contributions of 'service' and impact versus old-fashioned journal and conference publications?); constituencies (who do we want to engage with our work, and what kind of relationships do we want to have with them?); and support (what kind of work should funders and we as a research community put our dollars behind, and what kind of efforts do we want to support in this space?).

One response to the uncertainties above – let's call them mode 2 anxieties – is a retreat or nostalgia towards established disciplinary norms and practices, including more traditional or externally certified standards of quality and rigor. For first generation CSCW scholars who grew up in other academic homelands, some of these will be the disciplinary traditions we came from. This may account for at least some of the methodological anxieties that haunt the margins of scholarship in CSCW, information science, and related fields. Many of us find ourselves longing for worlds in which statistics are more rigorously practiced and understood, experiments are more precisely conducted, or higher and deeper standards of ethnographic work prevail (take your disciplinary pick). We may also long to see our students trained with the same depth and care that we received in our own core areas of work. Such concerns run deep and real, and must be taken into account under any serious engagement with the practice and politics of interdisciplinarity. One natural reflex under mode 2 conditions is thus to move or look backwards, escaping uncertainty and the epistemological tensions and anxieties it occasions by retreating to older or more settled systems for the production and validation of knowledge.

Another response, however, is to move forward – to make CSCW, in effect, 'post-normaler'. Under this model, CSCW would get less comfortable, and push forward into modes of work that the field has been less inclined to prioritize and reward to date. CSCW scholars would continue the trend toward deeper and more sustained engagement with cyberinfrastructure practice at the project level, with or without the near-term promise of publication. But they would also strengthen their efforts at higher levels of engagement, bringing CSCW insight to the shaping of science policy itself. This could take multiple forms: contribution to high level reports and science advisory activities (for examples to date, see [8, 24]); extended service at the NSF or other federal funders; and heightened participation in broader science policy processes in Washington, including at the White House (e.g. Office of Science and Technology Policy) and Congressional levels. Such engagements are best supported by modes of CSCW research that understand and embrace the policy world, building better bridges from CSCW's traditional interests in design, organization, and collaborative practice to broader policy questions around institutions, publics and governance that the field would do well to embrace.

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