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Integrated Circuits
Material, Social, Spatial

How much scientific knowledge should be accessible to the public? Does access and public input advance scientific research? These are central questions in Cyrus Mody’s brief history of information—that-sometimes-wants-to-be-free. He argues that a shifting social zeitgeist, particularly during the 1960s, propagated increasing degrees of transparency and cooperation within the scientific community. In a field where focused pipeline production and seemingly unproductive lines of inquiry have both yielded breakthroughs, he examines the pros and cons of open access and collective intelligence.

Cyrus C.M. Mody

Introduction

Most communities have annual celebrations that mark membership or promote solidarity: Passover, Fourth of July, commencements, shareholder meetings, county fairs. For American academic nanotechnologists, ‘NanoDays’ has become an annual ritual of their new, fragmented not-quite-discipline.1 Coordinated by the Nanoscale Informal Science Education network (NISE), it has evolved into a national event involving nearly 200 participating institutions, which invite the public into their labs to see how (and why) nano research is done.

Invitations to enter the laboratory are unusual in the history of science. Although scientists justifiably gesture to a tradition of open debate about technical matters, the laboratory space has been one of the least open aspects of the scientific enterprise. Until the twentieth century, much cutting-edge experimentation was conducted in scientists’ homes, and witnessed only by invited guests. In the last century, new research institutions, such as corporate and national labs, emerged as incubators for proprietary or classified knowledge, and as such were closed to the public.

Yet NanoDays indicates that current American policymakers believe the public (or some slice of it) is a welcome, even necessary, presence in the lab.2 This shift was evident when President Clinton announced the formation of a National Nanotechnology Initiative (NNI) in 2000, which encouraged nanoscientists to participate in public forums and proactively consider the societal implications of their work. Consequently, lab research is being supplemented by an array of humanistic and social scientific experiments designed to complete a feedback circuit between scientists’ knowledge of what is physically possible and what society desires from science. Such experiments include: having scientists write science fiction and future scenarios to understand the implications of their work; holding ‘consensus conferences’ to bring different nano stakeholders together to establish common ground; public opinion surveys (most of which show that the American public knows little about nano, is generally optimistic about it, but has some worries that are orthogonal to scientists’ own anxieties); and ‘citizens’ schools’ that introduce interested community members to the pros and cons of nanotechnology in the hopes they will become opinion leaders within their social networks.

Science and society, of course, have never been independent entities, and these experiments merely make explicit a relationship that has always existed to varying degrees. However, the model represented by NanoDays is a dramatic change from a Cold War ‘pipeline model’ in which the public was seen as a one-way consumer of expertise. In contrast, nanotechnology is one of the first fields to involve public input before the products of research enter the market, and even before research towards those products begins.

Like any experiment, these forays in public participation carry risks. Neither science nor politics can withstand perpetual, direct democracy, at least in modern America. The NNI seeks out institutions that can combine the knowledge and aspirations of different niches of science and society without amalgamating them into something less than the sum of their parts. Since at least World War II, the integration of scientific expertise and public priorities has co-evolved with the assimilation of different kinds of materials: organic and inorganic, wet
and dry, electrical and mechanical. The scale of the former is the human scale of collaboration, negotiation, habitation and protest whereas the scale of the latter is that of small handfuls of atoms measured in billionths (‘nano’) of a meter.

**Pipelines and Priorities**
Prior to World War II, the US federal government was not a dominant player in most scientific fields. But by the war’s end, federal support for research had grown dramatically, especially in areas related (even tenuously) to military objectives. West Virginia Senator Harley Kilgore pointed to federal management of wartime research (the Manhattan Project, penicillin production, radar, etc.) and asked whether something similar would work for civilian goals. He envisioned a ‘National Science Foundation’ where elected officials established priorities for American scientists and supported them in solving national problems.

In the end, Kilgore’s NSF was co-opted by a coalition of scientists, politicians opposed to social reform, and large businesses. Their vision for the NSF gave scientists autonomy to pursue ‘curiosity-driven’ research, with little pressure to address social concerns. Kilgore’s opponents (especially Vannevar Bush) posited a pipeline model that culturally and epistemically privileged ‘basic science’ conducted for the sake of exploration and judged only by disciplinary peers. The pipeline model moved knowledge linearly from basic science to ‘applied science’, ‘engineering science’, ‘development’ and finally ‘manufacturing’ of real-world technologies. Scientists at the beginning of the pipeline were regarded as producers of reliable knowledge and agents of liberal democracy because they were regarded to be least beholden to commercial or political interests.

The pipeline model was always, in Donald Mackenzie’s apt phrase, ‘an engine, not a camera’. It functioned poorly as a picture of how science actually works, but was effective as a means for bringing about changes in science policy. Elite universities such as Stanford, MIT, and Johns Hopkins liked it because it allowed them to use their discipline-oriented departmental structure to reap overhead fees from federal basic research contracts. Big high-tech companies such as IBM liked it because they could compete for the same federal contracts while getting tax breaks for every dollar they spent on basic research; they also liked that the twenty-plus year timeline required for an idea to move down the pipeline disadvantaged small companies dependent on constant cash flow. Cold War strategists liked it because they wanted to ‘stockpile’ scientists for some future conflict; they believed that large-scale, curiosity-driven funding would sustain these scientists’ morale in the interim.

**Moment of Relevance**
In the late 60s, the pipeline model broke down. It was attacked by many from the right, including Barry Goldwater, for making scientists dependent on government rather than the market. It was critiqued by the military’s Project Hindsight, which found virtually no weapon systems that benefited from basic science research. Liberals in line with President Lyndon B. Johnson’s social reform initiatives insisted that the backlog of basic research was big enough: scientists needed to start applying that knowledge to the ‘human problems’ of the day. Radicals demanded an end to the military applications that dominated what was coming out of the pipeline, but they also wanted an end to funding for basic – or what campus activists called ‘useless’ – research. They pressured scientists to demonstrate the relevance of their research to social problems – though who would judge their pertinence was always contentious.

The demand for relevance required scientists to come out of seclusion and interact with an increasingly engaged public. Politicians and campus activists called for researchers in universities and aerospace firms to join the anti-war movement by ‘reconverting’ from military to civilian topics; to acknowledge the civil rights movement by turning to ‘urban problems’; and to embrace the environmental movement by providing fixes for pollution, energy, and (more problematically) overpopulation. In tandem, many scientists and engineers faced pressure – even from their administrators and colleagues – to collaborate with counterparts from a wider range of disciplines. In some cases, these collaborations led to the novel integration of different materials at the micro- or nanoscale. For instance, if electrical engineers were to help solve ‘human problems’ in medicine, they needed to coalesce their discipline’s materials (e.g., silicon integrated circuits) with those of their physician-collaborators (e.g., human cells).

‘Human problems’ research also led to new collaborations among natural scientists, social scientists and engineers. The high-priority areas of the day, such as
issues in which social and technical factors intermingled, and economists' and sociologists' expertise would be as necessary as those of chemists' or civil engineers'.

Some scientists and engineers also began drawing on the humanities. Matthew Wisnioski describes the short-lived ferment of a time when Bell Labs' researchers read the Frankfurt School and worked with John Cage and Robert Rauschenberg. Superficially, such collaborations helped humanize technical disciplines tainted by association with the Vietnam conflict. On a deeper level, some scientists and engineers saw historical and philosophical expertise as necessary to reflect on the role of science and technology, and on how society's needs could be incorporated into technical decision-making.

A few collaborations succeeded, and even gave rise to institutions such as the 'Science, Technology, and Society' programs that sprouted on American campuses. Many collaborations, though, ended in frustration and distrust. Overcoming the linguistic, material, and cultural differences between disciplines proved more difficult than imagined, and little infrastructure existed to foster cooperation. The moment of relevance was so brief, and took place under such strained budgets, that there was little opportunity to build radically interdisciplinary work environments. Instead, scientists relied on shuttle diplomacy – spending a few days or hours in a colleague's lab, hoping to share enough knowledge to make collaboration productive.

Research and Resource

The sense of urgency dissipated with the end of the Vietnam conflict and the economic shocks of the 70s. It was chaotic while it lasted, marked by protest, wildly fluctuating budgets, and a withering of public confidence in scientists (and vice versa). In the aftermath, scientists pushed for the restoration of basic research funding on the grounds that problem-solving is inherently uncertain: the areas that in the long-run will yield solutions to national needs cannot be predicted.

Pressure once again eased for scientists to demonstrate their relevance to society, although budget constraints led federal funders to push scientists to obtain donated tools from companies (that in-turn benefited from tax breaks) and to get more value from their government-funded equipment. Federal agencies funded 'research and resource facilities' to support basic researchers, so long as they made equipment available to others as a national resource. This model was applied in fields as disparate as astronomy, particle physics, and vertebrate zoology. In the field of microfabrication, for example, Cornell received an NSF grant in 1977 for a National Research and Resource Facility for Submicron Structures – to be housed in a building paid for largely with private donations, stocked with federally-funded and corporate-donated instruments, and shared with researchers and companies outside Cornell.

In several of the fields now central to nanotechnology, such as surface science, microfabrication, and device physics, scientists during the 70s and 80s interacted indirectly with colleagues from other fields. In a given facility setting, scientists from several disciplines might share an instrument such as an electron microscope. Their co-presence near the same set of tools, and their common struggles in mastering those tools, meant that scientists could hardly avoid learning from each other, even if they were not directly collaborating. Still, through much of the 80s, incentives for scientists to integrate perspectives from other disciplines or the public were minimal compared to the late 60s. Engineers who once worked energetically with artists, musicians, physicians, and counterculture gurus now limited their outreach to chemists, physicists, and materials scientists. Molecular biologists who were once caught up in 'science for the people' movements now focused on becoming biotech millionaires. Indeed, the 80s brought a sense that the market, rather than humanistic reflection, would correct the pipeline model's shortcomings – by speeding up commercialization of knowledge, and by orienting basic researchers' curiosity to financial opportunities.

Fall of Communism, Rise of Biology

Increased competition forced companies like IBM and AT&T to de-emphasize curiosity-driven research in favor of shorter-term, commercially-viable innovation. The most celebrated high-tech companies of the 80s, such as Intel and Apple, were famous for doing little basic research, preferring to cherry-pick other companies' discoveries, while keeping their own researchers physically and intellectually close to the factory floor. In the 90s, IBM, RCA, and AT&T, among others, followed suit, either abandoning their 'hunting lodges of science' or retooling them for more product-oriented research.

The end of the Cold War also upended many policymakers' and scientists' perceptions of a hierarchy among disciplines, as evidenced by the demise of the Superconducting Supercollider (SSC) and the triumph of the Human Genome Project (HGP). The SSC, located in Waxahachie, Texas, was slated to be a $6 billion ($4.8 billion), 52 mile (84 kilometer) circumference exurban campus for high-energy physics research. During the Cold War, believers in the pipeline model placed this subfield atop the disciplinary hierarchy. Its claim to address the most 'fundamental' issues (the elementary building blocks of matter, the origins of the universe) and its remoteness from both market forces and civilian-related 'human problems' made it the most basic science imaginable. As a result, high-energy physicists were rewarded with megaprojects and influential positions in the nuclear weapons establishment. Post-Cold War America, however, demanded a 'peace dividend' that would divert defense expenditures into quality of life improvements. High-energy physicists' proximity to nuclear weapons and distance from civilian applications now worked against them. Meanwhile, the Human Genome Project knit a strong constituency more in keeping with public opinion by promising benefits to Americans' health, and by distributing its efforts over many disciplines and Congressional districts.

At the same time, big corporate labs like those at IBM and AT&T were becoming smaller and more product-focused, encouraging many of their top researchers in surface science, microfabrication and other future nanotechnology areas to leave for academic positions. As these new faculty began applying for federal grants, they could see that funds for biomedical research were soaring while money for the physical sciences remained flat. They also saw that Congress, partly on the basis of condensed-matter physicists' testimony against the SSC, was abandoning a hierarchical pipeline model of the scientific disciplines in favor of a more egalitarian model in which disciplines cooperated to move ideas back and forth between basic and applied domains. Thus, for those scientists who eventually became
nanotechnologists, bringing biological applications and expertise into their labs became a winning strategy. Where a typical microfabrication conference in 1980 would have almost exclusively featured talks on inorganic, crystalline materials, by 1994 the field was overrun with papers on ‘Tracking down Biological Motors Using Optical Tweezers’ or ‘Microfabricated Arrays: DNA Electrophoresis and Cell Mobility’. Device physicists began taking sabbaticals to help start-up companies use semiconductor chips for immunoassays and DNA fingerprinting, and surface scientists started regularly studying biological membranes deposited on their pristine surfaces.

**Nanotechnology Today**

For the NNI, nanotechnology has the potential to yield revolutionary benefits because the size regime below 100 nanometers is inherently amenable to interdisciplinary collaboration and to the convergence of basic and applied research. At this scale, the largest molecules of interest to chemists converge with the smallest molecules of interest to biologists, and the quantum phenomena of interest to physicists blur into the bulk phenomena of interest to engineers. In this context, it is also possible to consider curiosity-driven explorations (into quantum effects, for example) with the social benefit and economic viability of their potential applications.

The organizational form of the NNI is built on such convergence. It serves as an umbrella agency that sets nano-scale funding guidelines for two-dozen federal agencies – such as the NSF, Department of Defense and the National Institutes of Health. These agencies have concentrated their funding toward interdisciplinary academic centers, of which the NNI website proudly lists more than sixty, not including several coordinated by the NSF’s six Nanoscale Science and Engineering Networks. Most have a headquarters on one campus, with collaborators dispersed around the world and among many disciplines.

Some of the NNI’s founders explicitly view these academic centers as filling the gap left in American science when the labs of RCA, AT&T, IBM, GE and other big companies disappeared or re-toolled for short-term research. But even in the heyday of the pipeline model, corporate labs relied primarily on market-based measurements of how society viewed and judged their work. Federally-funded university labs, however, pursue a mix of basic and applied research, some of which may eventually reach the market, but much of which must be justified indirectly. Today’s science policy consensus is that these labs must create a face-to-face constituency for their work through ELSI experiments (consensus conferences, citizens’ schools, etc.) and through outreach programs such as NanoDays.

Some prominent nanoscientists feel these experiments do damage to the field by absorbing resources and telling the public unnecessary information about nano’s potential dangers. Likewise, representatives of nano-based businesses sometimes express the view that the only unethically direction for nanotechnology would be to delay it by dithering over the ethics of nanotechnology. Most social scientists involved in nano unsurprisingly take the opposite stance that there are moral and pragmatic reasons to create a feedback mechanism between nanoscientists and the public, lest the public perceive scientists as hiding the truth. This latter view is backed by robust social scientific findings that public opinion toward emerging technologies is more likely to remain positive if the public feels it has been informed about potential negative consequences of the technology.

Yet this essay’s historical sketch offers corrective to both ELSI’s skeptics and supporters. Skeptics should see that the era when the public had little role in technical decision-making has passed. The cloistered science of the pipeline model could not adapt quickly enough to the dramatic countercultural changes in American society of the late 60’s (especially the civil rights, anti-war and environmental movements). Many skeptics seem to believe that market forces are sufficient to make science responsive to society’s needs. Yet this view neglects the market’s negative influence on long-term considerations, and the reluctance by many in the private sector to conduct broad research that requires bearing the cost of externalities such as pollution and climate change.

ELSI supporters, meanwhile, need to look to history to reflect on their methods. The last great crest of public participation in technical decision-making resulted in chaos and the mutual disenchantment of scientists and a concerned and vocal public. The toughest question of late 60s science was: who would determine national priorities and decide what research is ‘relevant’? In other countries, this question was answered by the decision to centralize national science policy whereas in the US, the only answer thus far has been no answer. Because funding remains decentralized, scientists must find the agency whose priorities match theirs. Until experiments in public participation fully acknowledge this fragmentation, they risk manufacturing a mirage of engagement rather than its reality.

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1. NanoDays comprise a nationwide set of events that all take place within an annual one-week window. The events use materials sent to each site by NISNet, but the sites themselves decide how to conduct the events. Some of the events bring members of the public into the lab itself; others bring the public and local nanoscientists together at a science museum.

2. Support for public participation in science at the policy level seems to be pushed by program officers at the federal funding agencies, with bipartisan, if lukewarm, support from elected officials.


7. Circa 1990, biologists had had a longer, continuous history of working with scholars in the humanities and social sciences, stretching back to the Asilomar conference in 1975 and the creation of IRBs in reaction to the Tuskegee Syphilis Study and other early 70s scandals.