The Need for Greater Multidisciplinary, Sociotechnical Analysis: The Bioweapons Case

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> *The time when only a few states had access to the most dangerous technologies is past. Biological and chemical materials and technologies, almost always dual-use, move easily in our globalized economy, as do the personnel with scientific expertise to design and use them. The latest discoveries in the life sciences also diffuse globally and rapidly.*
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> —James R. Clapper, Senate Committee on Armed Services, 18 April 2013[1]

Director of National Intelligence (DNI) Clapper's statement to the US Senate last spring reflects concerns that have arisen in recent years about advances in biotechnology and their implications as bioweapons threats. For example, observers in the policy and intelligence communities have asserted that once-difficult biological techniques are becoming automated, routinized, and done by people with minimal technical expertise.[2] These developments point to a "deskilling" of biotechnology, a term signifying that complex skill sets, know-how, and practices may no longer be required to produce novel agents or materials. According to some, such deskilling could lead to a Wikipedia-style radical democratization of biotechnology expertise by making it possible for anyone "to design and fabricate biological systems without being controlled by any kind of authority."[3]

Others have described how high school and college students as well as independent "do-it-yourself" biology groups can use new scientific tools and techniques to construct novel biological materials.[4] In 2009 the National Security Council released its *National Strategy for Countering Biological Threats*, which emphasized that "with advances in biotechnologies continuing to be globally available, barriers of technical expertise and monetary costs will continue to decline, making a potent bioweapons capability available to many US adversaries."[5] Other reports colorfully suggested that bioweapons capabilities are accessible to "garage bio-hackers," "mad scientists," and "bio-criminals."[6]

Such perspectives reflect the concern since 9/11 that new scientific developments and the globalization and diffusion of biotechnology have given terrorists or hostile states an expanded store of weapons to use against the United States and its allies. Such threats should raise concerns, but scholars who study the

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development and diffusion of science and technology can't help but see in the public treatment of potential bioweapons threats the need for greater discussion of fundamental analytic issues concerning these threats. For example:

- How exactly do advances in the life sciences and biotechnology affect the nature of the bioweapons threat in coming years?
- What specific knowledge, skills, conditions, resources, and time scales enable the development of new biotechnologies and their weaponization?
- Moving from the global to the local, how can we better assess the ways in which a diverse set of actors may develop and use biotechnologies for harm?

To date, much is still not known about the fundamental drivers of emerging biotechnology and bioweapons threats, how they apply to specific actors and cases, and how these drivers are changing over time. Additional analytic challenges stem from the complexity of biological systems and the difficulty in predicting how innovations and discoveries in the life sciences and related technologies can be controlled and harnessed for misuse—and how, and to what extent, this is a different problem than that posed by older bioweapons threats. Until these fundamental issues are examined in depth, intelligence analysts will face blind spots in their bioweapons assessments, which may lead to future intelligence failures and poor national and international security policymaking.

These issues were discussed in a workshop composed of US and British scientists and social scientists held in London in September 2012. The workshop, which I helped arrange with the UK Economic and Social Research Council's Genomics Policy and Research Forum, addressed the issue of improving intelligence analysis of emerging biotechnology threats.[a] Also participating were current and former intelligence officers and policy officials. The workshop sought to:

- Examine new analytic approaches to take into account *both* social and technical factors in assessing emerging bioweapons and dual-use technological threats;
- Create a new, forward-looking dialogue and intellectual exchange between intelligence practitioners and academic experts on how both communities can think more holistically about bioweapons threats; and
- Challenge the conventional wisdom that substantive discussions of analytic methods for bioweapons threats can only occur in highly classified settings.

Competing Models of Analysis

A key panel at the workshop framed the challenge especially well. Entitled "Understanding the Emerging Life Science Landscape," the panel laid out two competing models for explaining innovations in biotechnology and the life sciences.[7] One, the "biotech revolution" model, was described by US Department of Homeland Security Deputy Assistant Secretary for Chemical, Biological, Radiological, and Nuclear Policy Gerald Epstein. This model emphasizes codified knowledge in biology and the material aspects of biotechnology and assumes that biotechnologies develop with a fixed linear or exponential technological trajectory.

Proponents of this model, such as those noted above, hold that biotechnologies will become more available due to the widespread geographical diffusion of biotechnology information, materials, infrastructure, and expertise across a wide range of commercial and academic settings. Biotechnology is seen as becoming more powerful, available, familiar, and decentralized. This model assumes that technology is the primary driver and that states, terrorists, or other nonstate actors will readily exploit modern biological materials and techniques to lower technical barriers, obviate existing controls, and create vulnerabilities for harm. Under this model,

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[a] A brief description of this meeting can be found at http://www.genomicsnetwork.ac.uk/forum/events/pastevents/workshops/title,26429,en.html. Funding support for the workshop and its participants was provided by the UK ESRC Genomics Policy and Research Forum and the National Science Foundation. The Genomics Forum is based at the University of Edinburgh and is part of the ESRC Genomics Network (EGN), a major ESRC investment spanning five of the UK's leading universities examining the development and use of the science and technologies of genomics.

the bioweapons threat is expected to grow rapidly in the future.

An alternative model, which could be dubbed the “biotech evolution” model, was presented by University of Sheffield Professor of Sociology Paul Martin. This model focuses on the complex social, economic, scientific, and technical factors that shape biotech innovation and its applications, factors that can powerfully moderate potential bioweapons threats.[8]

This model, based on decades of in-depth qualitative academic social science research, some involving longitudinal (20–30 year) case studies covering a range of biotechnologies, reveals a slower, multifaceted, and nonlinear model for biotechnology development than the biotech revolution model. This is because biotechnological development occurs within social, natural, economic, and political contexts, and as a result, biotechnologies can develop in a number of different ways. This analytic approach studies local technical practices as well as the larger laboratory, institutional, industrial, and environmental settings in which technologies are developed and used.

These studies reveal that in the small number of cases where specific biotechnology products and innovations have emerged and been successful, it was the result of many decades of incremental collaborative research. Typically, it has taken 35 years for new biotechnology innovations to mature and be useful. While these case studies focused on commercial biotechnology rather than biological weapons development, they reveal patterns that may be common to all life science developments. These scholarly case studies demonstrate a different picture and understanding of biotechnology and its patterns of innovation, diffusion, translation, and uptake that are worthy of serious consideration for intelligence.

Following are my suggestions for addressing the need for better conceptual models in this aspect of proliferation analysis. As a proponent of the second model discussed at the workshop, I will argue that a combination of social and technical—what I call ***sociotechnical***—multidisciplinary analyses of biotechnology is needed for a fuller understanding of the problem. I will draw on academic literature from the social science field of science and technology studies (S&TS) to illustrate how sociotechnical factors underpin the diffusion of biotechnology and bioweapons threats. I will conclude by proposing how teams of intelligence analysts and different analytical practices could be established to apply sociotechnical methodology to this important challenge.

The Technical Model

As I have written elsewhere, existing intelligence and policy understandings of biotechnology and the life sciences have tended to be based on the first model discussed in the September 2012 workshop and focused on the material and technical aspects of the problem.[9] As a result, the dominant analytic framework has had as its primary focus the following elements:

- Codified biological knowledge, i.e., information found in journal articles, scientific textbooks, websites, databases (for example, genome sequences), and other written sources;
- The material end products of biotechnologies
- The accessibility of biological materials (pathogens, oligonucleotides), biological supplies (reagents, prep kits), infrastructure (DNA synthesizers, laboratory benches), and other tangible items (monetary resources)
- The economic drivers of biotechnology
- The globalized and diffused character of biotechnology

The upshot of this analysis is a rapidly climbing threat trajectory

Absent or marginalized in this framework are the important aspects of the biological sciences and biotechnology addressed in the second model. These include:

- The important role of tacit knowledge—more commonly referred to as know-how—in biology. This know-how involves important social dimensions related to hands-on laboratory work that can often not be reduced to written form
- The real challenges of producing these materials, including troubleshooting efforts, context, and the manpower required to produce a stable biotechnology end product
- The social and material conditions required for biotech equipment to work in different local contexts (for instance, in an outpost in Afghanistan versus in an academic laboratory)
- Recognition that even biotech and pharmaceutical industries, with ready access to resources, have struggled to harness new biotech-

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nology developments for their specific applications[10]

- The role of specific social actors and how they can affect technology design, development, use, and transfer

Crucially, not only do the models consider different aspects of the problem, they will lead to different suggestions for intelligence and policy interventions.

Implications of the Technical Model

By framing the issue as a technical problem, the intelligence and policy communities appear to have placed the most attention on increasing within their ranks technical biological knowledge and expertise, and new programs and activities have focused on technical solutions.[11] In November 2006, the National Counterproliferation Center (NCPC) within the Office of the Director of National Intelligence (ODNI) established the Biological Sciences Experts Group (BSEG) to improve the Intelligence Community's access to biological expertise.[12] The BSEG grew out of high-profile public recommendations from the 2005 *Final Report* of the Commission on the Intelligence Capabilities of the United States Regarding Weapons of Mass Destruction, the National Academy of Sciences, and the US House of Representatives Subcommittee on Prevention of Nuclear and Biological Attack of the Committee on Homeland Security.[13]

The BSEG maintains a cadre of external life science and bioweapons experts from universities, companies, and nongovernmental organizations.[14] These experts serve as independent consultants to the NCPC and are appointed through the National Intelligence Council Associates Program. The BSEG charter states that members may be assigned the following types of projects:

- Supporting intelligence customers in the design of scientific/technical experimental protocols, intelligence analyses, or collection methodologies against biological threat agents, biological warfare agents, and/or state and nonstate actors that do or may pose threats to the United States
- Advising on strategies to improve the execution or interpretation of results of experimental protocols, analysis, and collection
- Undertaking technical assessments and performance reviews of the Intelligence Community's scientific/technical programs, analytical products, and collection methodologies[15]

The establishment of the BSEG has made new, in-depth scientific expertise available to the US Intelligence Community and made it easier for intelligence analysts to identify and call on specific outside technical experts to help assess the security implications of new biological developments.[a]

This technical focus of BSEG is consistent with past efforts to improve assessments, which have tended to focus on the technical domain. For example, in the early 1990s, the CIA created the Nonproliferation Center, an analytic unit that focused on the technical aspects of proliferation. In 2001, that center was replaced by a new and larger center, the Weapons Intelligence, Nonproliferation, and Arms Control Center (WINPAC).

With its creation, WINPAC centralized CIA's technical weapons specialists in both nonproliferation and arms control issues. The creation of the NPC and WINPAC increased institutional consolidation, segregation, and prioritization of technical expertise on bioweapons issues within the CIA. This technical orientation was further reinforced by the decision in 2010 to create a new Counterproliferation Center,[16] in which National Clandestine Service elements (handling the collection of technical information) and WINPAC elements were united.

Other intelligence units have also relied mainly on technical knowledge and expertise to inform bioweapons assessments. In 1998, the

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[a] Interestingly, BSEG members are hired through the National Intelligence Council (NIC) Associates Program, which was originally designed to bring multidisciplinary (typically social science) expertise to the CIA. But there is no indication that historians, social scientists, or relevant nontechnical experts have been incorporated into BSEG membership. Rather, the organizers of BSEG see the NIC Associates Program as a contracting mechanism to bring in technical experts, not as a source of valuable multidisciplinary expertise and different methodological approaches to study bioweapons threats. Anonymous US policy official, e-mail communication with author, 9 October 2010.

Defense Intelligence Agency created a science advisory group called BioChem 20/20. Its mission was to "lead and focus the defense intelligence community's assessments of emerging technologies that nation states or terrorists could use for biological or chemical warfare and to mitigate technological surprise from foreign biological warfare programs."[17]

The publicly available information concerning the above efforts suggests that left out of the organizational responses were relevant social science or other nontechnical experts who might have addressed the political, economic, and social dimensions underpinning technical work, including development of know-how, work disciplines, and interdisciplinary forms of weapons knowledge.[18]

Similarly, the dominant intellectual streams that have shaped understandings of weapons issues in the broader US security community come from science, engineering, and political science—the fields that have shaped strategic studies and terrorism studies.[19] Although they provide important tools and techniques for understanding weapons issues, these fields typically do not analyze the specific factors and mechanisms by which scientific and technological knowledge, work, and products can be shaped by social factors.

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Examples of Shortcomings from Existing Assessments

Assessments of developments over the past decade in the new technical field of synthetic genomics offer examples of the problems of such narrow technical analysis. In 2002, virologists at the State University of New York, Stony Brook, created a synthetic polio virus using commercially available materials and equipment and without using any natural viral components.[20] The description of this experiment in the open scientific literature raised policy concerns about the ease of acquiring and using biological materials, information, and techniques for terrorism.[21]

A closer analysis of the experiment, however, reveals how important particular kinds of know-how were in the preparation of the reagent necessary for a successful experiment. While acquisition of commercially available materials was relatively straightforward, creation of a particular reagent necessary for the experiment proved to be stumbling block.[22] The experiment only succeeded after the experimenters had developed the know-how—in this case a "sense" of the visual and sensory cues that allowed them to determine when the reagent had reached the stage that is was ready for use in the synthesis experiment.

Efforts to replicate the experiment by people without the sensory know-how have failed even with free access to materials and written protocols. Acquisition of these sets of know-how and related laboratory disciplines has proven difficult even for the small subset of national and international virologists who specialize in the polio virus. In sum, the polio virus synthesis experiment depended on the mastery of specialized and extremely difficult-to-achieve laboratory know-how and, contrary to popular assumptions, it could not be replicated by anyone who read the *Science* article about the experiment.

In January 2008, the J. Craig Venter Institute published a synthesis experiment that described the creation of a small parasitic bacteria, the *Mycoplasma genitalium* genome.[23] Although the experiment built on knowledge obtained in the Venter Institute's earlier laboratory work, the construction of the *Mycoplasma genitalium* genome was based on an entirely new approach.[24] Moreover, while this bacterial synthesis was a major advance because of the large size of the genome, the experiment took several years to come to fruition after a tedious, multistage process in which the Venter team—involving 10 researchers and help from three companies specializing in gene synthesis—had to build the genome one fragment at a time with many quality control steps along the way.

Thus, advances in synthetic genomics technologies and the commercial availability of biological materials have not eliminated the need for complex, specialized know-how and teamwork in advanced biotechnology work. If anything, experience is indicating that synthesis of larger genomes is actually getting more complicated, with a need for greater resources and additional manpower. A 2009 *Trends in Biotechnology* article has noted this complexity and the continued need for specialized skills for this emerging science: "Most multi-gene-engineering projects involve ad hoc methods of DNA assembly…. [E]mploying custom cloning strategies … [and] are labor intensive and difficult to automate."[25]

Experts in gene synthesis note that the problems that remain in gene synthesis are not necessarily about resources or money. Rather, the challenges are intellectual and require hands-on work, time, teams of experts, and new (still unknown) techno-organizational processes involving important social dimensions of technical work. These examples from the field of synthetic genomics further illustrate the need to look at the sociotechnical complexities of biological work. These examples also reveal how much is still not known about the fundamental drivers of the diffusion and standardization of biotechnologies.

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The Alternative: Creating New Sociotechnical Assessments

The social science field of S&TS has been developing the conceptual tools for studying how the science and technology behind emerging biotechnologies are shaped by social and environmental factors. This analytic approach involves detailed study of technical practices and related knowledge-generating activities in biotechnology and the life sciences, as well as the laboratory and institutional contexts in which this work is situated. This approach strives to understand how data construction, scientific work, and technologies are shaped by the skills, cultures, and routines of particular technical settings.

For example, S&TS scholars have studied the requirements and problems of moving scientific and technical knowledge to new settings.[26] Researchers have found that the transfer of technologies from one lab or technical setting to another often requires difficult adaptations. A successful translation often requires the presence of the original author or inventor of the technology to supervise or conduct the shift.[27] Although this transfer may also occur in the absence of its authors, under such conditions, the process becomes more challenging and time consuming.[28]

S&TS scholars have also focused on the importance of the "tacit" dimensions of scientific practice—or know-how. Probably one of the first academics to talk about this was Michael Polanyi, a chemistry professor who became a philosopher of science. He is the author of *Personal Knowledge* (1958) and *The Tacit Dimension* (1966), which argued that scientific knowledge was not reducible purely to material factors or pieces of explicit information but also required conceptual and sensory knowledge, which he called "tacit knowledge."[a]

S&TS scholars have since expanded the concept of tacit knowledge. Sociologist of science H.M. Collins wrote that tacit knowledge can consist of visual, sensory, and other unarticulated components and skills that are part and parcel of doing scientific work.[29] Thus, tacit knowledge refers to the unarticulated knowledge of researchers. Collins explains that tacit knowledge comes through practical, hands-on processes in two mechanisms, either through "learning by doing"—a painstaking trial-and-error process of individual discovery—or by "learning by example," as apprentices once learned from masters. Collins has also developed a useful set of categories of tacit knowledge that one can observe and document in scientific work, and he has shown how some of these types of know-how are more difficult than others to acquire and transfer.[30]

In looking at distinctions between codified (written forms of knowledge) and tacit knowledge, other sociologists of science have argued that the authors of step-by-step written scientific instructions in articles, textbooks, or manuals typically assume their readers will be competent practitioners who possess relevant know-how and the ability to troubleshoot and adapt the method to local circumstances.[31] Sociologist of science Michael Lynch, however, has found that even highly skilled practitioners are not able to competently carry out some scientific tasks without prior training in the specific lab in which a published technique was introduced, because of the particular local and personal dimen-

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[a] See the following article in this issue by Michael A. Dennis, "Tacit Knowledge and the Proliferation of Nuclear WMD." Michael Polanyi, *Personal Knowledge: Towards a Post-Critical Philosophy* (University of Chicago Press, 1958) and *The Tacit Dimension* (Doubleday, 1966); both books have been reprinted several times.

sions of scientific practice in that specific lab.[32]

A few studies have looked at communal forms of tacit knowledge—tacit knowledge developed within teams or organizations—that are involved in creating complex technologies.[33] For example, some S&TS scholars have emphasized the importance of close working relationships among various interdisciplinary specialists to create a working technology.

In these studies, however, the type of communal knowledge varies. For example, some describe prolonged interaction between different types of scientists that leads to the production of a new type of communally synthesized tacit knowledge that cannot be separated into individual components, and is therefore more difficult to transfer. Other studies seem to allow for a simpler model in which communal tacit knowledge is the mere addition of the knowledge resident within individual scientists and engineers; such knowledge could be separated out and then more easily reassembled.

Benjamin Sims, an S&TS scholar, at Los Alamos National Laboratory has highlighted the importance of what he describes as "transactional knowledge," which Sims defines as the organizational and management skills (know-how) necessary to coordinate practices across multiple technical communities. This type of know-how allows each community to contribute to a larger technological goal. Sims argues that this is an important form of tacit knowledge related to technical work that is often overlooked.[34]

Other scholars working in the S&TS field point to how it is easy to overlook the presence and persistence of tacit knowledge in technical work. For example, science studies scholar David Gooding explains how scientists or other technical experts can overlook the importance of their own tacit scientific practices:

> *For experiments and instruments that work: they work in a particular world that has been ordered and prepared in ways that retrospective accounts hide from view.…As procedures and pathways are mastered, so the skills that enable them drop out of the account. They lose visibility as they are worked into the repertoire of the shared, taken-for-granted practices of a particular community.*[35]

Because of such blind spots, it often takes the probing of outsiders to identify the know-how that underpins an experiment or technology.

In order to capture the tacit dimensions of technical work, S&TS scholars have used in-depth case studies. Typically, these studies consist of detailed historical or ethnographic data about scientific and technological cases that drive toward obtaining rich, in-depth understandings of the why and how of particular cases. The qualitative approach can make clear important contextual factors and understandings that quantitative and technical methods are unable to capture.

In applying this approach to analyzing emerging technologies and bioweapons, analysts would seek to study in detail:

- the specific factors, conditions, and time scales required to develop tacit knowledge in the biotechnology of concern
- the kinds of social engineering required (e.g., pedagogy, exchanges, management structures, etc.) for the development of tacit knowledge in the field
- the means by which tacit knowledge is transmitted locally and globally—or, conversely, the factors that prevent its transmission, including particular local conditions and unique practices
- the causes of failure, too often overlooked in studies[36]
- the conversion of tacit knowledge to codified knowledge

Scholars of science and technology have emphasized the need to study the social dimensions of how technology travels, including its micro and macro-level features.

S&TS scholars have emphasized the need to study the social dimensions of how technology travels, including its micro- and macro-level features. For example, James Cortada, a historian of information technology, has discussed how computer technologies have been spread throughout the United States and the world.[37] He found that contrary to the popular assumption that the diffusion of IT knowledge is a special case, it actually resembles in many of its features the diffusion of other technologies across many countries and eras. He argues that conclusions about IT diffusion have been made prematurely, without adequate research into the contributions of social, economic, political, legal, technical, and infra-

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structure factors. For example, he lists critical government interventions and the existence of important constituencies around the world (e.g., programmers, service providers, vendors, users, academics, and multinational corporations).[38]

Cortada's work illustrates the importance of multidisciplinary analysis of technologies. Because many developments in emerging biotechnologies have been described as paralleling IT, Cortada's work cautions on drawing early and simple conclusions about the patterns and implications of biotechnology diffusion and suggests doing in-depth, longitudinal case studies to look at both social and technical dimensions of biotechnology development and use.

Recommendations

How might the Intelligence Community better take into account both social and technical factors in assessing new technologies? Some mechanisms appear to exist and simply need to be applied. One is the Red Team approach, in which outsiders would specifically challenge dominant technical approaches and analytic practices. A Red Team might place particular importance on understanding in qualitative, micro-level fashion the social dimensions of a scientific and technological problem, including tacit knowledge; organizational and management styles; translation and adaptation of techniques and technologies to a local context; and relevant training and laboratory practices.

Such an effort would require a Red Team to focus on specific people, in specific places, with specific materials, in particular social contexts, and with localized practices, and the analysis of their interactions. I believe this approach would promote a creative, flexible, multidisciplinary knowledge environment if sufficient resources and authorities were granted to conduct in-depth analysis.

A February 2005 Intelligence Science Board study on collaboration in intelligence suggested the creation of interdependent work teams of analysts that would be

> *collectively responsible for a significant piece of analytic work—work that…can be larger in size and potential significance than usually is possible for a task performed by any single individual. Members of work teams bring their own special expertise to the work, of course, and over time evolve specialized team roles—but it is the team as a whole that produces and is accountable for the analytic product.*[39]

The report also proposed creating teams composed of members with different expertise and specialties in order to "foster the kinds of cross-functional exchanges that…result in unanticipated insights and syntheses."[40] This kind of work team would also be expected, encouraged, and enabled to draw on other internal and external experts for short- or long-term consultations and contractual work as needed.

Such a team, a sociotechnical work unit within the counterproliferation community, would inject greater multidisciplinary approaches to thinking about biotechnology or any technology of proliferation concern. This approach to knowledge-making would better account for the messy and contingent aspects that characterize the development of weapons technologies and would result in more holistic assessments of bioweapons threats.

Initiatives along these lines should be supported by government and non-government funds. Within the US intelligence community, the National Intelligence Council and the Department of State's Global Futures Forum—with track records of engaging with diverse experts in the academic community in unclassified settings—would be naturals in advancing this conversation on a larger scale. In addition, the ODNI's BSEG could be modified to include more disciplines for academic intelligence discussions

With new biotechnologies come new challenges for intelligence collection and analysis. With a more multidisciplinary approach to these challenges, intelligence analysts can develop more accurate and holistic understandings of how biotechnologies develop, spread, and are used. With greater insights, analysts will be better able to help policymakers identify better measures to address threats from emerging biotechnologies, and indeed from any emerging technology.

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Endnotes

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