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Tacit knowledge: The concept and its implications for biological weapons proliferation

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I. Introduction

1. At the Seventh Review Conference, States Parties agreed to "promote common understanding and effective action," including "developments in the field of science and technology [S&T]."[1] A common understanding of the concept of "tacit knowledge" may be helpful in future discussions between States Parties on the potential implications of developments in S&T. Tacit knowledge is relevant to biological weapons proliferation because it partially determines the ease with which a potential proliferator can produce biological weapons. Section II describes the concept of tacit knowledge historically. The relevance of tacit knowledge to biological weapons production and proliferation is further discussed in Section III. Section IV explores the impact of advances in S&T on the relevance of tacit knowledge, using examples of recent developments in S&T as case studies.

II. Historical definition

2. The concept of tacit knowledge was first proposed by the Hungarian scientist and philosopher Michael Polanyi in his 1958 text, "Personal Knowledge: Towards a Post-

[1] United Nations, Final Document of the Seventh Review Conference, BWC/CONF.VII/7 (13 January 2012), available online http://www.unog.ch/80256EDD006B8954/%28httpAssets%29/3E2A1AA4CF86184BC1257D960032AA4E/$file/BWC_CONF.VII_07+%28E%29.pdf

Critical Philosophy."[2] Polanyi defines tacit knowledge as "a wide range of not consciously known rules of skill and connoisseurship which comprise important technical processes that can rarely be completely specified."[3] Polanyi argues that the sum total of these "rules" constitutes an individual's tacit knowledge – the skills, understanding, and intuition gained "through the process of unconscious trial and error by which we feel our way to success and may continue to improve on our success without specifiably knowing how we do it."[4] Unlike explicit knowledge, which can be acquired by reading or following written protocols, tacit knowledge cannot easily be recorded or codified. Examples of activities that rely in part on tacit knowledge range from the ability to ride a bicycle to the ability to successfully transplant a heart. Both sets of skills require practiced action to acquire.

3. Polanyi contends that tacit knowledge can be individual or collective. Individual tacit knowledge is idiosyncratic and can be transferred through direct observation or imitation.[5] Individual tacit knowledge can be either acquired through transfer or gained autogenously through extensive trial-and-error. In the case of the latter, the constant repetition of a process, and the subsequent refinement of the skill, creates tacit knowledge. Communal tacit knowledge can refer either to the compounded knowledge of all members of a collaborative group or, in some instances, to the unique dynamics and interactions that facilitate how a group or organization can collectively accomplish a complex task.[6] The concept of communal or collective tacit knowledge has been explored extensively, particularly in the work of Donald Mackenzie and Graham Spinardi, who examined its role in the context of nuclear weapons creation, and Kathleen Vogel and Sonia Ben Ouagrham-Gormley, who examined it with respect to biological weapons creation.[7]

4. Polanyi further argues that tacit knowledge serves a critical role in the daily practice of science.[8] One common example is the ongoing challenge faced by many microbiologists in culturing bacterial species. For instance, the average culture-positivity rate for samples collected from patients with *B. pertussis* ranges from 20 to 83 percent. This suggests that while some laboratories can culture the bacterium approximately eight out of ten times, other labs can do so just twice out of ten attempts, despite access to the same publicly available information on the culturing of *B. pertussis*. This significant variation in the ability to successfully culture the bacterium is due to a number of factors, among them the differences in tacit knowledge – i.e., "the expertise and familiarity of laboratory personnel with *B. pertussis* culture."[9]

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2 See Polanyi, Michael. *Personal knowledge: Towards a post-critical philosophy*. University of Chicago Press, 2015 e-book edition [first published 1958.] available (for purchase): http://www.amazon.com/Personal-Knowledge-Towards-Post-Critical-Philosophy-ebook/dp/B00XVQOPHO. The concept of tacit knowledge has been examined and expanded upon extensively in the last fifty years. For a recent exploration of the concept, see Collins, Harry. *Tacit and Explicit Knowledge*. University of Chicago Press, 2010.

3 Polanyi, *Personal Knowledge*, e-book edition pg. 1680

4 Polanyi, *Personal Knowledge*, e-book edition pg. 1639

5 Vogel, Kathleen. "Bioweapons Proliferation Where Science Studies and Public Policy Collide." *Social Studies of Science* 36, no. 5 (2006): 659-690.

6 MacKenzie, Donald, and Graham Spinardi. "Tacit knowledge, weapons design, and the uninvention of nuclear weapons." *American Journal of Sociology,* (1995): 44-99.

7 See MacKenzie and Spinardi, *Tacit Knowledge*, 1995; Vogel, *Bioweapons*, 2006; and Ouagrham-Gormley, Sonia Ben. "Barriers to bioweapons: Intangible obstacles to proliferation." *International Security* 36, no. 4 (2012): 80-114.

8 Polanyi emphasizes "how greatly these sciences [chemistry, biology and medicine] rely on the transmission of skills and connoisseurship from master to apprentice." E-book edition, pg. 1515

9 Doern, Gary V. "Detection of selected fastidious bacteria." *Clinical infectious diseases* 30, no. 1 (2000): 166-173.

III. Relevance to biological weapons proliferation: Increasing or decreasing risk

5. Understanding the role of tacit knowledge in biological weapons production is critical for States Parties to accurately assess the risk of proliferation and devise appropriate strategies of prevention. While preventing the illicit spread of materials and equipment is imperative, successful proliferation requires not only the acquisition of biological materials and equipment, but also the direct involvement of individual scientists with the knowledge necessary to craft the weapons. Analyses such as Vogel's show that written knowledge alone may be insufficient for a party to develop biological weapons, and that the acquisition of tacit knowledge may well be necessary. Tacit knowledge may therefore significantly impact overall proliferation risk. This section will examine tacit knowledge as a risk modulator, evaluating its role in decreasing or increasing the risk of biological weapons proliferation.

Role of tacit knowledge in the risk of BW proliferation

6. Lack of tacit knowledge can decrease the risk that a proliferator can produce biological weapons, as possession of biological materials, equipment, and methods in the absence of individuals with tacit knowledge greatly stymies development of such a weapon.[10] One illustration of the impact of tacit knowledge on weapons production is the failure of the former terrorist organization Aum Shinrikyo to create viable biological weapons with the bacterium *Clostridium botulinum*. Aum had assets estimated at close to one billion U.S. dollars, access to extensive laboratory equipment, and a group of 15 dedicated scientists.[11] These scientists possessed academic degrees in fields including chemistry, virology, and medicine, all of which should have provided enough knowledge to follow published protocols on agent production.[12] Despite these resources, Aum was unable to successfully culture or disperse a virulent strain of *C. botulinum* – or any other pathogen. [13] Tacit knowledge played a clear role in this failure: "While extracting the deadly agent… is a simple operational detail conceptually, it is not so easy to perform operationally. If Aum scientists understood this bench laboratory technique, they were apparently not able to perform it."[14]

7. The transient nature of tacit knowledge can also decrease the risk of biological weapons production. Tacit knowledge is fundamentally temporal; the knowledge is held by a given individual or group and, unless passed on directly, is lost with the demise or departure of the person or group.[15] In instances where tacit knowledge is not directly transferred, it is lost. As the number of states engaging in offensive biological weapons

[10] Simply culturing many virulent biological agents remains difficult. For instance, despite existing naturally in soil, *Francisella tularensis* is notoriously difficult to grow in laboratories, with a positive culture rate as low as 10%. See Taylor, Jeffery P. et al. "Epidemiologic characteristics of human tularemia in the southwest-central states, 1981–1987." *American journal of epidemiology* 133, no. 10 (1991): 1032-1038.

[11] Tucker, Jonathan B. Toxic terror: Assessing terrorist use of chemical and biological weapons. MIT Press, 2000.

[12] Danzig, Richard et al. *Aum Shinrikyo: Insights into How Terrorists Develop Biological and Chemical Weapons*. Washington, DC: Center for a New American Security (2011). Available at: http://www.cnas.org/files/documents/publications/CNAS_AumShinrikyo_SecondEdition_English.pdf

[13] John Parachini, "Aum Shinrikyo," in Brian Jackson et al., *Aptitude for Destruction, Volume 2: Case Studies of Organizational Learning in Five Terrorist Groups* (Santa Monica, CA: RAND, 2005) p. 20.

[14] Parachini, *Aum Shinrikyo*, pg. 20

[15] MacKenzie and Spinardi, Tacit knowledge, 1995

research dwindles, so too will opportunities for an individual to observe and practice the skills necessary to craft a biological weapon. Moreover, the longer a former bioweapons scientist goes without practicing his or her skills, the less useful those skills are. [16]

8. The acquisition of tacit knowledge (e.g., through access to experienced experts) increases the risk of successful weapons production using materials to which a proliferator may already have access. Unlike nuclear, chemical, radiological, and conventional weapons, the raw materials of biological weapons are abundant in nature. For example, in the United States, *Francisella tularensis* is found across the Northeast, and *Yersinia pestis* is found across the Southwest.[17] Further, the equipment needed to craft a biological weapon is largely the same as that used for legitimate purposes in laboratories around the world.[18] The difficulty in crafting a biological weapon therefore lies not only in the acquisition of materials or equipment, but also in the acquisition and application of appropriate expertise, including tacit knowledge. *Transfer* of tacit knowledge through interaction with experienced experts who have previously mastered such knowledge is generally the surest and most efficient way to acquire needed skills, and can facilitate a proliferator's efforts. Tacit knowledge can also be developed *de novo* given sufficient time and effort; however, this is likely to substantially increase a proliferator's costs, increase the risk of failure, and delay the development of a BW capability.

IV. Effect of advances in science and technology (S&T)

9. There are divergent viewpoints on the effect of advances in science and technology on the role of tacit knowledge in biological weapons production and proliferation. The first contends that as technology becomes cheaper, more accessible and – critically – more user-friendly, the role of tacit knowledge as a proliferation barrier is diminished.[19] One example is the gene-editing technology CRISPR[20], which uses RNA sequences to cheaply and easily edit genomes. Affordable, comparatively easy-to-use technologies like CRISPR may erode the necessity of tacit knowledge.[21] Similarly, the increased availability of open source, "dual use" information in new formats could provide a new avenue for the transmission of tacit knowledge, and decreases the need for direct, in-person access to experienced

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[16] Polanyi contended that tacit knowledge not actively used would be lost within "the period of a generation;" Vogel and others have argued that significantly less time is needed for tacit knowledge to lapse. See Polanyi, *Personal Knowledge,* ebook pg. 1471; Vogel, *Bioweapons,* p. 673

[17] The same is true of toxins. Ricin and abrin are both derived from relatively common plants and pufferfish can be a source of the potent neurotoxin tetrodotoxin. [See Yotsu, Mari et al. "Production of tetrodotoxin and its derivatives by *Pseudomonas* sp. isolated from the skin of a pufferfish." *Toxicon* 25, no. 2 (1987): 225-228.]

[18] See Selgelid, Michael J. "Governance of dual-use research: an ethical dilemma." *Bulletin of the World Health Organization* 87, no. 9 (2009): 720-723. Available online at: http://www.scielosp.org/scielo.php?pid=S0042-96862009000900017&script=sci_arttext

[19] Tucker refers to this erosion of tacit knowledge as "de-skilling," in which the level of tacit knowledge required to successfully use a technology gradually declines over time, until finally the technology is easily usable by anyone. See Tucker, Jonathan B. "Could terrorists exploit synthetic biology." *The New Atlantis* 31(2011): 69-81.

[20] CRISPR refers to "Clustered Regularly Interspaced Short Palindromic Repeats." For more information on CRISPR, see http://www.sciencemag.org/site/extra/crispr/?intcmp=HP-COLLECTION-PROMO-crispr.

[21] Carlson, Robert. "The pace and proliferation of biological technologies." *Biosecurity and bioterrorism: biodefense strategy, practice, and science* 1, no. 3 (2003) p. 109

bioweapons scientists.[22] This argument is explored in depth by Jamie Revill and Catherine Jefferson, who argue that – while tacit knowledge remains an "important sociotechnical [aspect] of biotechnology" – the traditional difficulties associated with transferring tacit knowledge in person have been substantially reduced by advancements in communication technologies.[23] As an example, they cite the growing use of video tutorials to demonstrate common biological laboratory techniques. These videos provide access to knowledge that could previously be accessed only through direct observation and experience.[24] Revill and Jefferson are careful to note that an increase in publicly available, "dual use" information does not automatically equate to an increase in the threat of bioterrorism.

10. The second, contrasting viewpoint contends that while developments in science and technology may make certain sets of tacit knowledge obsolete, they also often create a new and distinct body of tacit knowledge. New technologies must be learned and often require a period of trial-and-error to work through glitches and resolve performance problems.[25] Resolving these problems requires not only a specific set of skills and expertise, but also often relies on past experience resolving similar problems. This problem-solving results in the creation of new tacit knowledge. For instance, the 2010 synthesis of a synthetic bacterial genome by the Venter Institute, while hailed as breakthrough in biotechnology, was successful in large part due to the expertise of a large team of "highly skilled and experienced molecular biologists" capable of using trial and error to invent new protocols.[26] These new protocols comprised new sets of tacit knowledge, which in turn must be learned and shared. It should be noted that this argument is predicated on humans as the primary conductors of science. As Robert Carlson and others argue, the automation of processes involved in the routine conduct of life sciences research may eventually force a reassessment of the role of tacit knowledge in preventing weapons production and proliferation.[27]

V. Conclusion

11. Tacit knowledge, defined as the set of skills and understanding gained only through direct experience, is an important consideration in assessing the risk of biological weapons production and proliferation. Tacit knowledge serves as a risk modulator. The proliferation of this kind of knowledge, even without the corresponding proliferation of materials, may increase the overall risk of biological weapons proliferation, while its temporal nature may decrease the associated risks. Advances in the automation of biological processes may eventually render some sets of tacit knowledge obsolete, but in

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[22] Revill, James, and Catherine Jefferson. "Tacit knowledge and the biological weapons regime." *Science and Public Policy* 41, no. 5 (2014): 597-610. Available online at: http://spp.oxfordjournals.org/content/41/5/597.full

[23] As mentioned, Revill and Jefferson's argument pertains specifically to the increased ease of *transferring* tacit knowledge, not to an erosion of the importance of tacit knowledge itself. They state that "to conduct an assessment [of threat] premised solely on material capacities, such as…the availability of codified information (in for example scientific journals) alone… ignores the very real and grounded difficulties experienced in the process of doing science…" Revill & Jefferson, *Tacit knowledge*, p. 598.

[24] The *Journal of Visualised Experimentation* has over 2,000 such videos. Revill & Jefferson, *Tacit knowledge*, p. 604.

[25] Vogel, Kathleen M. "Framing biosecurity: An alternative to the biotech revolution model?." *Science and Public Policy* 35, no. 1 (2008): 45-54.

[26] Tucker, Synthetic Biology, 2011

[27] Carlson, Robert. "Tracking the Spread of Biological Technologies." Bulletin of Atomic Scientists (2008). Available: http://thebulletin.org/tracking-spread-biological-technologies

the interim the learning of additional technologies creates new forms of tacit knowledge. The transfer of tacit knowledge related to biological weapons production remains a potential threat to international security, and States Parties should address the concept in order to effectively develop strategies to mitigate its proliferation. Sharing a common understanding of what constitutes tacit knowledge can serve as a foundation for future discussions on the risks stemming from developments in science and technology.