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SECURITY IMPLICATIONS OF A STATE-DRIVEN APPROACH TO SCIENCE AND TECHNOLOGY INNOVATION

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Introduction

The key and ever-increasing roles of science, technology, engineering, and mathematics (STEM) innovations are evident across the spectrum of security realms.[1] STEM applications in weaponry include a broad range of advances in sensor technologies, materials sciences, and artificial intelligence (AI), to name just a few. In the broader arena of human security, fields such as satellite technology, energy harvesting and conversions, water treatment, and health/medicine continue to improve and innovate due to both greater understanding of the natural world and ever-growing capabilities to meld, merge, and apply diverse areas of scientific knowledge into integrated technological systems.

Almost all technologies have the capacities to be used for good or ill. Technologies are value-neutral, and it is the governance choices—how the technologies are used—that determine whether technologies are boons or burdens to humanity. Many end up being both.

In virtually all advanced Western nations, and in most countries around the world, STEM growth and the direction of scientific and technological progress is primarily based on and directed by practicing scientists and engineers, rather than by central authorities. While governmental support of scientific and of technological innovation often is substantial, the decisions on what research to pursue are largely left to the professional scientists in universities and corporations. Hereafter, these approaches will be referred to as scientist-driven systems of science and technology governance. In such systems, while scientific misconduct including ethical breaches occur, the self-correcting nature of an observant, honest, and skeptical scientific community has resulted in widespread adherence to international scientific standards, including the applications of science in technological innovations.

In contrast, in a state-driven scientific enterprise the directions and priorities of scientific and technological research are determined by political leaders, rather than by scientists. The most notable example of such a state-driven system is that of the People's Republic of China (PRC).

Using a focused, sustained, government-driven prioritization of STEM in service of its Communist Party interests, the PRC's STEM education, workforce, and productivity capabilities have grown rapidly over recent decades. And in contrast to the above-noted intermittent misconduct by individual researchers and/or corporations in scientist-driven systems, the PRC government has systemically engineered the acquisition of STEM capacities via illegal methods, has violated norms and standards of the scientific enterprise, and has used its STEM capabilities to advance its national interests in defiance of international rule of law and to the detriment of its own, its neighbors', and the world's environments.

The dependence of security progress on STEM innovations, combined with these contrasting models of STEM advancement—state- vs. scientist-driven—therefore is a topic of considerable concern for security practitioners.

Growing STEM Roles Throughout Security Realms

Science and its application in technologies have deeply shaped both military and broader human security. From the earliest discoveries of ways to forge stronger metals, to the development of gunpowder, to the weaponization of microorganisms, increasingly sophisticated STEM understanding has enabled and supported innovations in the use of hard power.

At least equally important from a broad human security perspective, STEM innovations have propelled virtually every improvement of humanity's well-being. Development of the germ theory of disease, for example, reduced the burden of a host of communicable illnesses that plagued the world for centuries. Understanding of Newtonian physics underlies much of our modern architectural and transportation systems; Einsteinian refinements of that knowledge continue to drive astronomy and cosmology. Advances in empirical and theoretical chemistry allow the extraction and/

or synthesis of compounds central to modern-day life, from concrete, to gasoline, to pharmaceuticals.

In parallel, security issues shape scientific and technological development. Military arms races are perhaps the most obvious example, but needs and desires to improve food, water, and health security have engendered scientific innovations.

In advancing human progress, scientists internationally have come to agree on certain core scientific values and practices, including skepticism, openness of communication, and, most importantly, honesty. Scientists recognize that the falsification of data or manipulation of results to present a picture contrary to facts damages the integrity of the entire scientific enterprise and undermines the public confidence on which science depends. Actions such as fabrication of data and plagiarism of others' work are intolerable in the scientific community, as they undercut science's core values and the processes that lie at the heart of scientific progress. The adherence to theses scientific values, or the failure to do so, has significant ramifications across the broad spectrum of security arenas.

The Scientist-Driven Model

Throughout much of the world, this sort of open, honest STEM has been pursued by a broad spectrum of actors, including individual scientists and engineers, private organizations, and states. Governments, along with philanthropists, corporations, and industry associations, have supported scientist-driven STEM education and development. Only intermittently in these states have governments attempted to impose particular directions. In the United States, President Kennedy's push for a manned moon landing by the end of the 1960s stands out as one of the few occasions of a strong, sustained U.S. governmental directive and commitment to a specific technological goal.

This model of scientist-driven STEM arose following World War II. In particular, Vannevar Bush, in his *Science, The Endless Frontier* 1945 report—a "brilliantly articulated rationale and blueprint for an implicit social contract between the government and the scientific community"[2]—outlined an approach to U.S. STEM development that put much of the control and direction of science in the hands of the scientists themselves. Bush argued persuasively that professional scientists were better positioned than the national government to perceive, interpret, and respond to public needs and desires for scientific and technological innovations. His suggested approach was adopted by the United States and, with some adjustments to fit various national contexts, by most other nations.

While this scientist-driven system has undeniably had myriad positive impacts both within individual nations and internationally, the approach has also incurred some significant costs. For example, the United States' STEM-based industries make its *per capita* carbon footprint among the largest in the world, and result in it being a leading contributor to human-induced climate change. And various U.S. STEM-based accidents, oversights, and events, such as Love Canal[3] and the Union Carbide disaster in Bhopal, India,[4] further illustrate problems associated with this scientist-driven approach to advancing science and technology.

The State-Driven Model

Science and technology have played critical roles during various phases of China's history.[5] For the first half of the twentieth century, however, China's STEM contributions were minimal; the country was essentially a non-player on the global stage of STEM accomplishments.

But at least since the 1960s, the PRC government has taken control of the scientific enterprise, and used STEM to advance its own priorities. In recent decades, the PRC has invested ever-larger amounts of human, material, and financial capital into rapidly developing a wide range of scientific, engineering, and technological capacities. This focused, consistent, and strategic approach has been carried out to make its economy a "major center of innovation by 2020" and "global leader in science and innovation" by 2050.[6] The PRC's last two five-year plans have emphasized science and technology, along with technological innovation.

While the cultural revolution shut down universities and sent scientists to be 'rehabilitated' through manual labor in the remote countryside, the PRC simultaneously (in 1964) launched the "two bombs, one satellite" program, supporting and advancing national defense-related science such as nuclear, rocket, and satellite research. This sort of specific governmental direction of science explicitly to promote national interests stands in stark contrast to the decentralized, democratic approach described above that was and is prevalent in much of the rest of the world.

China's science and technology push has been fueled by governmental encouragement of higher education starting in the 1980s. In 1982, only

0.8% of Chinese aged 25-29 had any post-secondary education. By 1990, this rose to 3.3%, by 2000 to 6.7%, and by 2010 had leaped to 20.6%, increasing by over 25 times the 1982 rate in less than 30 years.[7]

In parallel, in 1986, the establishment of the PRC's National Natural Science Foundation was followed soon after with the 863 Program, the State Hi-Tech Development Plan. In 1995, yet another government plan, Project 211, began to upgrade the capabilities of almost 100 universities, spending an estimated US$2.2 billion over 1996-2000. This push was expanded in 1998 with Project 985, wherein the PRC invested nearly US$300 million each in enhancing its premier Peking and Tsinghua Universities over 1999-2001; such generous governmental support has continued since then to build world-class elite universities in China.[8]

The number of universities more than doubled in China, from 1,022 in 1998, to 2,263 in 2008; during this same time, virtually all of the pre-existing universities also were upgraded.[9] The quality of PRC universities is growing, especially in targeted fields. For 2017, in the field of engineering, Tsinghua University was rated[10] fourth (MIT was first); in sciences, Beijing University was 22nd (Berkeley was first); in computer science, Tsinghua University was 25th (Stanford was first); in mathematics, China had four universities among the top rated 50.

In 1998, the PRC began the Chanjiang Scholars program, to entice Chinese-born scientists living overseas to return for short-term visits to the homeland. In 2008, this development was expanded into the Thousand Talents program that offered generous support and incentives to bring foreign-residing scientists to live and work in China. By 2012, the program had lured more than 2,200 scientists back to work in the PRC, including nationally and internationally prominent scientists, members of the U.S. National Academy of Sciences, and more.[11]

These parallel efforts of external recruitment and internal bootstrapping of intellectual talent have been supported and complemented by increasing provision of resources to the science and technology enterprise. In 1991, the PRC invested in research and development (R&D) at a rate of only about 5% of what the United States spent. By 2010, that rate had risen to 44% of the U.S. rate. This 20% per year growth in R&D gross expenditures as a share of the gross domestic product contrasts with the virtually flat rate of spending on R&D over 1991-2010 in the United States.[12]

These strategic, sustained, and leveraged investments have paid off handsomely. The PRC is the fastest growing country in the world in terms of peer-reviewed STEM journal articles produced; its average annual growth rate of 19% over 2003–2013 clearly swamps that of other nations: 10% for South Korea, 7% for the United States, 5% for the European Union, and 1% for Japan.[13]

The payoff is more than simply academic. In various technologies, China now ranks among world leaders. The PRC boasts the world's fastest bullet train, Fuxing; the largest radio telescope, FAST; and launched its first domestic space station, Tiangong-1, in 2011.[14]

In 2016, the PRC launched 15 "Science and Technology Innovation 2030 Megaprojects," and in 2017, added "AI 2.0"—to make the PRC the world leader in AI by 2030—as the 16th of these projects. Also in 2017, the China Shipbuilding Industry Corporation and the University of Science and Technology of China began collaborating on quantum technologies supporting development of advanced naval mission systems. This "significant move to increase investment and promote industrialisation in forward-looking and disruptive technologies" will build three laboratories, for quantum navigation, quantum communication, and quantum detection.[15] The PRC's Baidu now employs more than 2000 researchers, and has offices in Seattle and Silicon Valley.[16]

China's STEM investments have been accompanied by, and are likely a significant factor in, its equally impressive economic growth. China's current economic might relative to the more modest economies of most other nations allows it to wield extensive influence throughout the region. The PRC has used this economic power, for example, to acquire long-term leases of key port facilities in Sri Lanka and Samoa, to advance its national goals in United Nations' considerations,[17] and in other security-related manners.

China's Misuse of STEM: Security Implications

Beyond the STEM-fueled economic leverage noted above, in a wide range of other STEM and security-related areas, the PRC's nationalistic focus costs its Indo-Pacific neighbors. Two examples will suffice.

In the build-up and militarization of Mischief and other nearby coral reefs in the Spratly Islands of the South China Sea, the PRC used its technological strengths to quickly turn these unique ecological treasures into airstrips and other military equipment installations. While the PRC's Foreign Ministry claims "necessary defense" as a justification, and refers to them as "primarily maritime safety and natural disaster support facilities,"[18] the United Nations' Permanent Court of Arbitration ruled in 2016 that Mischief Reef is part of the Philippines' Exclusive Economic Zone and, further, that China's island-building activities had breached multiple articles of the United Nations Convention on the Law of the Sea.[19] Yet China continues its illegal occupation of Mischief Reef and island-building activities. This is a clear example of how the PRC uses its enhanced scientific and technological capacities to advance its own interests in defiance of the international community, as well as to the detriment of the natural environment.

China has used these same scientific and technological capabilities to build multiple dams on the Mekong and other regional rivers; through its control of Tibet, the PRC now exercises control of the headwaters of 10 out of the 11 major rivers in southern and eastern Asia. These dams are impacting river flow rates, temperature, aquatic and floodplain flora and fauna, and the livelihoods of many tens of thousands of Asian residents downstream.[20] While climate change is undoubtedly a factor, bringing more frequent and intense droughts to the lower Mekong, the reality of its flow being at its lowest level in 100 years illustrates the "weaponization of the Mekong's waters"[21] that further highlights China's defiance of abiding by a rules-based order of international relationships.

Along with other authoritarian regimes, the PRC is considerably less concerned with violations of data privacy than is the U.S. government and democratic nations. Its much more widespread gathering of personal information, with far fewer restrictions on the use of such data has multiple, broad, and obvious security implications, particularly given China's abysmal record regarding United Nations-approved human rights of its own citizens.

Coincident with the recent rises in STEM investment and publication, China has displayed a growing rate of plagiarism, scientific fabrication, and other scholarly corruption among its researchers and publications.[22] The strong governmental control of the country's scientific enterprise combines high status and incentives for scientists and engineers who focus on national priorities, and a lax administrative evaluation of scientific and technological processes, setting up precisely the conditions for corruption and scientific fraud.

The PRC's weak regulation of scientific integrity has human security consequences. The international scandal in 2008 over China's melaminecontaminated milk that sickened more than 50,000 children[23] is a classic example how poorly regulated research and development can have disastrous impacts on public health.

In a related vein, it has recently come to light that a number of PRC scientists working in sensitive and cutting-edge fields in United States' laboratories have not revealed their sometimes very deep and substantial ties to PRC party and quasi-governmental organizations. The PRC has taken advantage of the open United States and international systems of science to acquire technological capacities via 'plagiarism' on a widespread, international scale.

Further, China's disregard for environmental safeguards[24] and existence of multiple 'superfund'-type sites[25] highlight how its state-controlled enterprises are dedicated to accomplishing PRC short-term goals while ignoring the broader and longer-term concerns of its own and other nations' peoples. Moreover, China's poor STEM industry regulation has led it to be the world's leading producer/releaser of atmospheric carbon, contributing more than one quarter of the entire world's emissions in recent years.[26]

Implications of STEM Governance Systems

The scientist-driven system of STEM tends to ensure that technologies are generally employed in manners more or less aligned with the values that underlie science—skepticism, openness, and honesty. The applications of state-driven STEM, on the other hand, reflect the political objectives, morals, and ethics of the political entity that drives them.

The PRC's STEM advancement, determined and driven centrally by a political party, stands in marked contrast to the broadly-adopted approach of empowering STEM professionals to largely delineate the path of scientific and technological progress. The meteoric rise of the PRC in STEM capabilities over recent decades, in comparison to the slower growth of U.S. and other Western countries' STEM capacities, thus poses a quandary for security professionals: Does this rapid growth in the PRC's STEM capabilities indicate the desirability of a stronger role for government in determining the directions for STEM advancement? Should Western governments adopt a more centralized, focused approach to supporting STEM?

More profoundly: What are, and what should be, the relationships between STEM and security? What are the implications, both nationally and internationally, of centralized governmental control of both STEM and the security sector? Going forward, how can and should the international community of Indo-Pacific nations respond to the PRC's continuing use of STEM in flaunting scientific norms and disrupting the international order?

These are not simple questions to address, nor do they have neat, clean answers. Regarding the first, now and going forward, it is clear that the STEM and security fields are evermore inexorably linked. STEM advances will shape the security arena, and security concerns will drive STEM advances. A healthy, vigorous public dialogue about both arenas, and the ways that they interact, will be key to the continued success of both. Governmental direction, as opposed to government regulation, of STEM can lead, as it has in the case of the PRC, to both serious abuses of international scientific norms and outright violations of international laws.

Addressing the second query, while it could be argued that more national governmental control of STEM direction could lead to more rapid advances in critical technologies, the downsides of such centralization that were raised above for the PRC must be kept in mind. The scientist-driven system in the United States enabled it to achieve and maintain dominance in STEM for a number of decades; its STEM higher education system is still globally admired, and is pursued by many thousands of foreign nationals each year. Such an approach that has proven so successful for such a long time should not be changed or abandoned without significant public consideration. The short-term gains of the PRC's STEM enterprise seem impressive, but may come at the cost of decreased public confidence in science and technology. The 2019-2020 coronavirus outbreak serves as an example of how governmental control of STEM, via such processes as surveillance and censorship of scientists, can be detrimental to broader human security. Additionally, this outbreak illustrates how state direction of the scientific enterprise can undermine the integrity of scientific processes, and potentially destroy both the credibility and productivity of the entire STEM undertaking.

The third question is even more problematical than the first two. A coordinated, consistent response from a broad coalition of states, at a minimum, will be needed to curtail PRC abuse of standards and norms, in both the STEM and international relationship realms. How to build such a coalition, given the diverse interests of the multiple parties in such a grouping, is, of course, a significant challenge; China has established deep relationships, including very substantial economic ties, to many Indo-

Pacific nations, and these alliances make criticism of or push-back against the PRC problematical on various levels. This challenge, however, must be pursued, or the PRC will surely continue to flaunt, in ever-more flagrant ways, the international norms and break the accepted rules, in whatever manner it sees to its own advantage.

If the integrity of the greater scientific enterprise is to be maintained, the larger issues of the relationships between STEM and security must be continually examined and openly debated among the broadest range of stakeholders, especially including professional scientists, rather than determined by political considerations. Only open, democratic dialogue will ensure the health and vitality of this enterprise that has nurtured the current state of well-being for humanity.

Conclusions

The development of science and technology have long both contributed to and been impacted by the broad spectrum of security issues. STEM advances have played critical roles in warfare and in the rise in living standards during peaceful eras. And this deep interweaving of STEM and security appears only to be increasing as we move into the future. Given these trends, changes of any Indo-Pacific power's STEM capacities will inevitably have impacts on myriad aspects of security across other Indo-Pacific states.

Increasingly and rapidly over recent decades, the PRC has built up massive scientific and technological capabilities. Governmentally-directed and strategically-focused, these capacities have targeted nationalistic goals without regard to the broader global community. The PRC has demonstrated its willingness to ignore both international rule of law and core principles of ethical scientific practice. It ineffectively regulates its own internal technology development, and uses its STEM power at the expense of broader regional human and environmental well-being.

A long history of vibrant STEM growth among states that largely empower researchers to determine the directions of their investigations illustrates the value and power of this scientist-driven system of STEM governance to people everywhere. This model has brought a plethora of benefits to humanity, while the scientific enterprise's self-correcting nature has ensured a relatively low cost.

In contrast, the PRC's state-driven approach to STEM, wherein a single political entity directs the education and applications of science and technology for its own ends, illustrates clearly that this approach, while enabling rapid growth in STEM capabilities, leads to the misuse of science and technology to the detriment of these enterprises themselves, as well as to direct harms to both people and the environment at large.

Going forward, the international community of Indo-Pacific nations must work in concert, responding emphatically to the PRC's continuing flaunting of scientific norms, disruption of the international order, and damage to our shared environment. Regional security professionals, as well as governments and the larger human community, must more closely monitor, condemn, and actively push back against the PRC's misappropriation and misapplication of its STEM capacities.

Notes

1 This widespread and critical importance of STEM to security is recognized within the United States and internationally, by groups such as the U.S. Department of Homeland Security (https://www.dhs.gov/science-and-technology/our-work), the U.S. Centers for Disease Control (https://www.cdc.gov/about/24-7/), the United Nations Office for Disarmament Affairs (https://www.un.org/disarmament/topics/scienceandtechnology/), and the European Association for the Study of Science and Technology (https://easst.net/article/science-technology-and-security-discovering-intersections-between-sts-and-security-studies/).

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