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SPRING 2023

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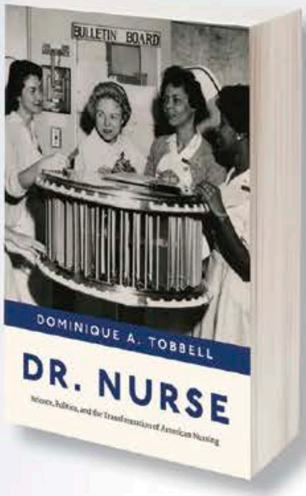
Science, Politics, and the Transformation of American Nursing

Dominique A. Tobbell



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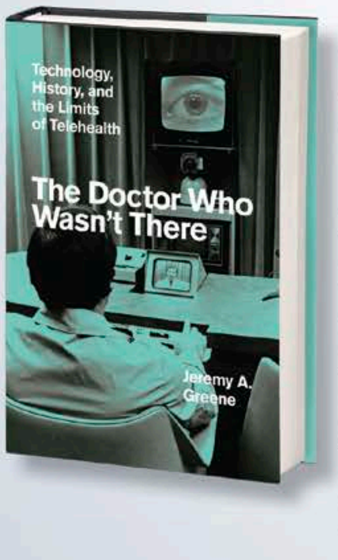

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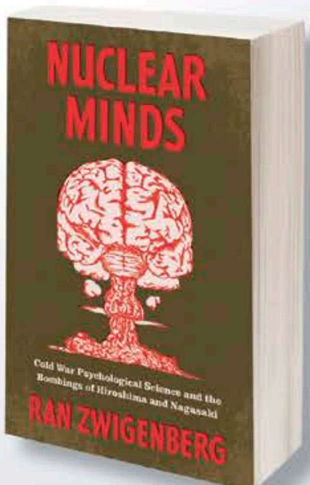

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Cold War Psychological Science and the Bombings of Hiroshima and Nagasaki

Ran Zwigenberg

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DEPARTMENTS

ON THE COVER: ANICKA YI, *Living and Dying in the Bacteriacene*, 2019. Installation view: *Symbionts: Contemporary Artists and the Biosphere*, MIT List Visual Arts Center, Cambridge, 2022. Courtesy the artist and Gladstone Gallery. Photo by Dario Lasagni.

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JEAN SHIN, *Freshwater,* 2022.

SUPPORT CAREGIVING SCIENTISTS

In "Fixing Academia's Childcare Problem" (*Issues*, Winter 2023), Zeeshan Habeeb makes what social scientists call the "business case" for providing subsidized childcare to graduate students and postdoctoral fellows. The author notes that the poorly paid, protracted training period for establishing an independent faculty career overlaps with women's fertility. Habeeb argues that this life course pattern plus the lack of affordable childcare on campus pushes out talented academics in science, technology, engineering, and mathematics—the STEM fields—and decreases the innovation, competitiveness, and profitability of the United States. Losing these highly trained early-career scientists is a poor return on the nation's investment in education and academic research.

However, the business case for work-family accommodations mostly persuades those who are already sympathetic. Others are likely to critique the statistics and to maintain that their institution is *different* from those held up as case studies.

Let's ask why the current arrangements—that require academics to work for low wages and without adequate family accommodations until their thirties or forties—are still so taken for granted in American universities. To understand this, we need to address four moral and emotional dimensions of academic STEM culture, as Erin A. Cech and I find in our book, *Misconceiving Merit* (University of Chicago Press, 2022).

First, academic science is not seen by STEM faculty as a business. Rather, it is understood to be a vocation devoted to fundamental research and largely unpolluted by profit or politics.

Second, our research shows that across genders and family statuses, STEM faculty largely embrace the "schema of work devotion," which mandates undivided allegiance to the scientific calling. Research faculty love their work; it is a big part of their identity. STEM faculty celebrate their independence and inspiration, charting their own course to intellectual discovery.

Third, seen through a work devotion lens, the lengthy training period is an appropriate novitiate, in which novices prove their dedication and their worthiness to be appointed as professors.

Fourth, the underbelly of work devotion is the stigma faced by caregivers, who are seen as violating their vocation. This translates into a devaluation of women and of non-gender-normative men, who often take on more of the household's caregiving responsibilities.

I encourage disciplinary and multidisciplinary associations and federal funders to address this stigma head-on. They should demand a moral reckoning, which would redefine STEM academics as deserving of the time and resources to have or adopt children, if they choose, while maintaining their respected status in the vocation. At a later life course stage, STEM academics also deserve the time to care for elderly or fragile parents and other loved ones, while still maintaining full respect for their scientific contributions.

Academic science is understood to be a vocation. To preserve the inclusion of early-career scientists who are creative and procreative in all senses of these words, let's stop expecting it to be a monastic one.

Mary Blair-Loy
Professor, Department of Sociology
University of California, San Diego

LESSONS FROM THE UKRAINE-RUSSIA WAR

Ukraine's response to Russia's invasion is reshaping our understanding of modern warfare along with defense research and development. At the same time, it presents an opportunity for already strong allies to forge new pathways of collaboration across the public and private sectors to bring commercial technology to the future battlefield. With help from public and private organizations, the Ukrainian armed forces

FRESHWATER

An installation by Jean Shin

Known for her large-scale installations and public sculptures, South Korean-born artist Jean Shin transforms accumulations of discarded objects into powerful monuments that raise awareness of the complex relationships between material consumption, collective identity, and community engagement. Shin, who was raised in the United States and works in Brooklyn and the Hudson Valley, often works cooperatively within a community or region, amassing huge collections of an everyday object or material while she researches its history of use, circulation, and environmental impact. Distinguished by this labor-intensive and participatory process, Shin's poetic yet epic creations become catalysts for communities to confront social and ecological challenges.

Shin's recent installation, *Freshwater*, is an example of how she amplifies the meaning embedded in everyday objects and creates a platform for community engagement and discussion. Freshwater was commissioned to be presented as part of *Water Marks*, a public art program along the Delaware Waterfront, presented by Philadelphia Contemporary in partnership with the Delaware River Waterfront Corporation. The centerpiece of Freshwater is a fountain that doubles as a living laboratory, offering visitors a view of local freshwater mussels filtering water piped directly from the Delaware River. In the fountain, chains of hand-blown glass vessels created by glass artist Alex Rosenberg are suspended from the ceiling, each containing a living freshwater mussel. The curved glass of the vessels magnifies the mussels as they anchor themselves in the sand and filter the water (each mussel can clean up to 15 gallons per day), rendering an overlooked species visible to the public eye. The stream of water flowing through the vessels culminates in a mirrored basin of clear, purified water that is then returned to the river.

According to the organizers, "Freshwater is haunted by the specter of industrial overconsumption and waste that have depleted freshwater mussel populations in the Northeast United States, as well as other major watersheds across the country. In the nineteenth century, the pearl button industry obliterated freshwater mussel populations in the Midwest, while in the Northeast, industrial pollution poisoned the Delaware River for a generation. Responding to this history, the basin

JEAN SHIN, *Freshwater,* 2022; freshwater mussels, glass vessels, sand, water pumped from the Delaware River, vintage mother-of-pearl shell buttons, metal basins, plexi mirror, and cables; dimensions variable. Installation at Cherry Street Pier, Philadelphia, Pennsylvania. Commissioned by Philadelphia Contemporary. Curated by Kerry Bickford.

of the *Freshwater* fountain is draped in blankets of thousands of vintage pearl buttons, all salvaged from warehouses along the East Coast. Each button represents a mussel that was harvested to create decorative items that were, until their incorporation into this project, never used. As we gaze into the mirrored portions of the fountain's basin, we are invited to witness ourselves as part of the balance between the past devastation reflected by the buttons and the present revitalization on display in the vessels above."

Photographs by David Evan McDowell.

have quickly embraced both military and civilian technologies as a means to confront fast-changing battlefield realities.

In "What the Ukraine-Russia War Means for South Korea's Defense R&D" (*Issues*, Winter 2023), Keonyeong Jeong, Yongseok Seo, and Kyungmoo Heo argue that the "siloed," "centralized" South Korean R&D defense sector should take a page from Ukraine's playbook and better integrate itself with the broader commercial technology sector. The authors recommend prioritizing longer-term R&D challenges rather than the immediate needs of the South Korean

JEAN SHIN, *Freshwater,* 2022.

armed forces, focusing innovation in critical technologies on new conflict scenarios and dynamic planning over the long run.

In recent years, South Korean policymakers have increasingly recognized the defense sector as a key area for advancing the country's security and economic interests. Propelled in part by many of the same government-led policy support mechanisms that have made the country a global leader in telecommunications, semiconductors, and robotics, South Korea has become the fastest-growing arms supplier in the world, with arms exports reaching more than $17 billion in 2022. Yet as Jeong, Seo, and Heo note, South Korea's defense community still faces obstacles to effective adoption of nondefense technologies that have played an important role in Ukraine, such as 3D printing, artificial intelligence-based voice recognition and translation software, and commercial space remote sensing. What's more, South Korea's failure to develop an inclusive R&D environment has hindered innovation in the nation's defense ecosystem. Large companies account for almost 90% of sales among defense firms, leaving little room for smaller, innovative enterprises to find success in the Korean defense ecosystem.

The United States faces many of the same challenges. A 2021 report from Georgetown University's Center for Security and Emerging Technology argued that under the US Department of Defense's current organizational structure, "defense innovation is disconnected from defense procurement," which is hampering efforts to adopt novel technologies at scale. Like its South Korean counterpart, the US defense industrial base is also characterized by high levels of market concentration among top defense contractors.

Jeong, Seo, and Heo offer recommendations that closely align with recent Defense Department efforts to foster innovation and accelerate adoption of the technologies that are fast transforming the US national security landscape. In light of lessons learned in Ukraine, the South Korean and US militaries should work together to develop and adopt disruptive technologies, ultimately enabling a joint fighting force in the Asia-Pacific region capable of deterring and defeating future adversaries.

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EXPORT CONTROL AS NATIONAL SECURITY POLICY

In 1909, as part of the Declaration of London on the Laws of Naval War, a group of nations produced a list of items we would today consider "dual use," but at the time were called "conditional contraband." The list was the first time a large set of states had agreed to a common understanding of what goods and technologies represented a security concern.

Interestingly, the list included an item that is not on current export control lists, but is very much on the minds of people engaged in security governance today: balloons. Like general aviation airplanes, box cutters, or novel genetic sequences, balloons, such as the ones floating over the United States recently, represent a type of security concern that is not really visible to, and therefore governable by, today's conventional export controls. But they still represent security concerns to the state.

In "Change and Continuity in US Export Control Policy" (*Issues*, Winter 2023), John Krige and Mario Daniels discuss how a historical gaze allows us to better understand "the context, effects, prospects, and challenges of the Biden administration's current policy changes" on export controls. But there is a bigger conversation about export controls that we seem unable to have: when is this system of governance not the right tool for the job?

Many aspects of the modern export control system took shape in the 1940s. What was once primarily a concern of the movement of goods from seaports is now about the movement of those goods, and the knowledge around them, from computer ports and laboratory doors. Krige and Daniels amply critique the central idea in much current export control policy: that security comes from preventing foreign supply. And the view that we can know what we need to be concerned about with enough time to put export controls in place—at least two years if you want to have international harmonization—doesn't need that much inspection to find many areas where it doesn't fit anymore.

Just five years after nations produced that first international lists of goods and technologies that represented a security concern, the concept of conditional contraband essentially fell apart in World War I and the era of total war. While export controls may not be on a similar precipice at the moment, their limitations are becoming only more apparent. In recognizing these limitations, we open the window to thinking differently about whose security matters, what counts as a security concern, and who has responsibility for doing something about it. Krige and Daniels note the obstacles the current export control policies will likely encounter, but it is also worth noting that we can capitalize on these obstacles to have a bigger conversation on when export controls are not the right tool for the job—and what the right tool might look like.

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"National security" is a beguiling concept. Who does not wish to be secure among one's people? Yet the very idea of a secured nation, as well as the instruments to achieve it, is not so much about the safety and well-being of the people in a country but the maintenance and expansion of state power, often at the cost of such safety and well-being. The normalization of national security obscures its contested origin and the violence it invokes.

As John Krige and Mario Daniels elucidate in their essay, national security as a whole-of-society response to perpetual danger grew out of institutional legacies of World War II and quickly took hold at the onset of the Cold War. Export controls have been central to this mission: to keep US adversaries technologically inferior and economically poorer, hence militarily weaker.

Since the beginning, export control regulations have faced pushback from proponents of free trade. Yet the dual objectives of a secured nation and a free market are in tension only if one believes in the fairness or at least neutrality of the capitalist market, and mistakes the purported ideals of America for reality. The so-called liberal international order, including financial systems, intellectual property regime, and trade rules, overwhelmingly favors US corporate interests and aids its geopolitical agenda. Export controls are another set of tools in service of US hegemony.

A country's foreign policy cannot be detached from its domestic politics. During the Cold War, US policymakers wielded the threat of communism as justification to wage wars and stage coups abroad, and to suppress speech, crush unions, and obstruct racial justice at home. Export controls should be understood within this broader context: more than just directing what can or cannot move across borders, these exclusionary policies also help define the borders they enforce. Both within and beyond the territorial bounds of the United States, the interests of capital and stratification of labor follow a racialized and gendered hierarchy. Export control policies reflect and reinforce these disparities; they are exercises of necropolitics on a global scale: to dictate who may live and who must die.

By the parochial logic of techno-nationalism, safety from dual-use technology is achieved not by restricting its harmful use but by restricting its users. Guns are good as long as they are pointed at the other side. The implications of this mindset are dangerous not just for existing technology but also for the future of science, as the anticipation of war shapes the contours of inquiry. When the Biden administration issued sweeping bans on the export of high-end semiconductor technology to China, citing the potential of "AI-powered" weaponry, the military application of artificial intelligence was no longer treated as a path that can be refused with collective agency but as destiny. The lust for a robot army further distracts from the many harms automated algorithms already cause, as they perpetuate systemic bias and aggravate social inequality. The securitization of a national border around knowledge depletes the global commons and closes off the moral imagination. The public is left poorer and less safe.

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THE SOCIAL SIDE OF EVIDENCE-BASED POLICY

"To Support Evidence-Based Policymaking, Bring Researchers and Policymakers Together," by D. Max Crowley and J. Taylor Scott (*Issues*, Winter 2023), captures a simple truth: getting scientific evidence used in policy is about building relationships of trust between researchers and policymakers—the social side of evidence use. While the idea may seem obvious, it challenges prevailing notions of evidence-based policymaking, which typically rest on a logic akin to "if we build it, they will come." In fact, the idea that producing high-quality evidence ensures its use is demonstrably false. Even when evidence is timely, relevant, and accessible, and even after researchers have filed their rigorous findings in a clearinghouse, the gap between evidence production and evidence use remains wide.

But how to build such relationships of trust? More than a decade of findings from research supported by the William T. Grant Foundation demonstrates the need for an infrastructure that supports evidence use. Such an infrastructure may involve new roles for staff within policy organizations to engage with research and researchers, as well as provision of resources that build their capacity to do so. For researchers, this infrastructure may involve committing to ongoing, mutual engagement with policymakers, in contrast with the traditional role of conveying written results or presenting findings without necessarily prioritizing policymakers' concerns. Intermediary organizations such as funders and advocacy groups can play a key role in advancing the two-way streets through which researchers and policymakers can forge closer, more productive relationships.

Research-practice partnerships, which consist of sustained, formalized relationships between researchers and practitioners or policymakers, are one way to create and reinforce the infrastructure for supporting relationships that advance evidence use. Such partnerships are especially common in education, where they often bring together universities and school districts or state education agencies to collaborate on developing research agendas, communicating findings, and interpreting evidence.

Crowley and Scott have demonstrated an innovative approach to creating relationships between researchers and policymakers, one that is well suited to deliberative bodies such as the US Congress, but which could also apply to administrative offices. In the Research-to-Policy Collaboration model the authors describe, the Evidence-to-Impact Collaborative operates as an intermediary, or broker, that brings together researchers and congressional staff in structured relationships to create opportunities for development of trust. These relationships are mutually beneficial: they build policymakers' capacity to access and interpret evidence and allow for researchers to learn how to interact effectively with policymakers. Thanks to their unique, doubly randomized research design (i.e., both policymakers and researchers were randomized to treatment and control groups), Crowley and Scott are able to demonstrate that the Research-to-Policy Collaboration model has benefits on both sides.

It is past time to move beyond the idea that the key to research use is producing high-quality, timely, relevant, and accessible evidence. These qualities are important, but as Crowley and Scott have shown, the chances of use are greatly enhanced when research findings are examined in the context of a trusting relationship between researchers and policymakers, fortified by the intermediaries who bring them together.

Adam Gamoran
President
William T. Grant Foundation

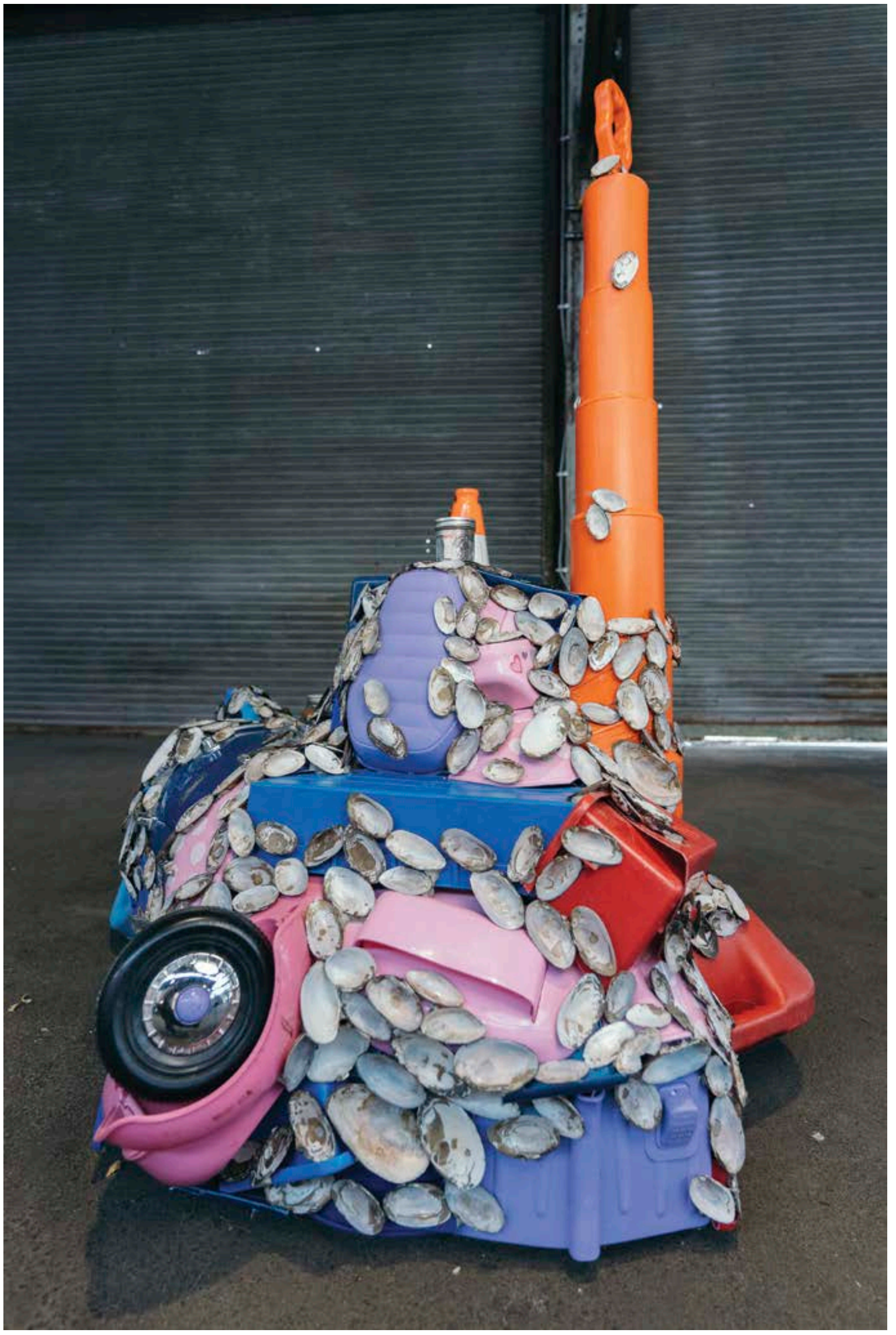
CARING FOR PEOPLE WITH BRAIN INJURIES

In "The Complicated Legacy of Terry Wallis and His Brain Injury" (*Issues*, Winter 2023), Joseph J. Fins employs the story of one man to underscore a severe shortcoming in the US health care system. Disorders of consciousness (DoC) are conditions of the brain when there is not brain death but there also is not consistent responsiveness to external stimuli. People who experience DoC may progress through coma, unresponsive wakefulness, and minimally conscious states before sleep/wake cycles are re-established and reliable responsiveness to external cues return.

People who experience prolonged DoC following traumatic brain injury encounter multiple faults in the existing service delivery system. Despite recent evidence that three of four persons with DoC due to traumatic brain injury will become responsive by one year after injury, many families are being asked to make decisions regarding withdrawal of life supports just 72 hours after injury. These families cannot be expected to know about prognosis; it is the responsibility of the health care system to provide unbiased and evidence-based data upon which these critical decisions can be made.

It is also incumbent upon the health care system to provide competent care tailored to the needs of persons with prolonged DoC. At discharge from trauma services, care by professionals who are competent to assess and treat unresponsive patients is obligatory. With the promulgation of guidelines by a joint committee of the American Academy of Neurology, the American Congress of Rehabilitation Medicine, and the National Institute on Disability, Independent Living, and Rehabilitation Research, we can no longer claim ignorance regarding the competencies needed to treat this population.

Tailoring care to the needs of people with DoC also includes placement in health care settings that can optimize rehabilitative treatments while protecting against complications that limit recovery. Movement to and between a long-term care facility and specialized inpatient rehabilitation programs should not be based on criteria developed for other populations of patients. For instance, there is no medical basis for the requirement that a person with a DoC *actively* participate in rehabilitation therapies when passive motor and cognitive interventions are the appropriate care. Effective and humanitarian treatment requires monitoring and coordination across a number of health care settings including, in some cases, the patient's own home. A person with a prolonged DoC deserves periodic reassessment to assure that complications are not developing and, more important, to detect when an improvement in arousal or responsiveness necessitates a change in therapeutic approach. This type of coordinated approach across settings is not a strength of the US health care system.



JEAN SHIN, *Freshwater,* 2022.

Other Western countries—most notably Great Britain and the Netherlands—have recognized the unique needs of persons with prolonged DoC and have designed health care pathways that optimize the opportunity for a person to attain their full potential. It should not be a matter of luck, personal means, or a relentless family that conveys the opportunity to regain responsiveness after prolonged DoC. We have the knowledge to provide appropriate care to this population; it is now a matter of will.

John D. Corrigan
Professor, Department of Physical Medicine & Rehabilitation
The Ohio State University

As I read Joseph J. Fins' essay, I was trying to envision the article's optimal target audience. As a neurologist who cares for critically ill patients with acute brain injuries from trauma, stroke, and hypoxic-ischemic brain injury after cardiac arrest, the clinical details of cases such as described are familiar. But this story is of a person, not a patient, and it reinforced the view that my particular domain, the neurological intensive care unit, has afforded me. People such as Terry Wallis and their families have a complex journey that involves direct and indirect intersections with intensive care units, skilled nursing facilities, rehabilitation facilities, hospitals, outpatient clinics, and insurance payors (governmental and private), as well as with the doctors, nurses, therapists, administrators, social workers, ethicists, and interest groups that inhabit these organizations, and with legislators who craft policies that overarch all. Mr. Wallis's poignant story seems to be one of disconnection. I would like to think that each of these groups that needs to hear this story has good intentions, but there is a clear lack of ownership, follow-through, and "big picture" that may even incentivize leaving those with severe neurologic impairments (or more often their families) to find their own way.

Several potentially disparate aspects of cases such as Mr. Wallis's bear discussion and emphasize the need for a holistic patient-centered view of his experience. These include prognostic assessment by medical personnel, values-based judgment of living a disabled life, and the civil rights that consciousness necessitates. It is increasingly recognized that inaccurate early negative prognostication can lead to a self-fulfilling prophecy of death or poor outcome if care is limited as a result of this assessment. Medically, prognostic uncertainty can be considered as the difference between "phenotype" (what a patient looks like on clinical examination) and "endotype" (the underlying biological mechanism for why the patient looks like this). The author's discussion of cognitive-motor dissociation is part of this consideration, as is clinical humility in prognostication (as described by the neurologist-bioethicist James Bernat). The comment that Mr. Wallis's treating doctors "couldn't imagine that the life he led was worth living" is also a common paternalistic view that pushes clinicians away from patients and diminishes the value of patients' and their families' goals of care. And perhaps most novel for treating physicians, the idea that civil rights of patients with impaired consciousness might be compromised if desired care is not accessible and provided is compelling and difficult to rebut. It is too easy for patients with disorders of consciousness to get disconnected.

A recent study by Daniel Kondziella and colleagues, reported in the journal *Brain Communications*, estimated that 103,000 overall cases of coma occur in the United States annually. Efforts such as the Neurocritical Care Society's Curing Coma Campaign seek to push the science toward recovery and bring a more holistic view of the care of patients across their experience. The story of Terry Wallis is not a one-off. I hope his journey can get to the audiences who need to hear.

J. Claude Hemphill III
Professor of Neurology
University of California, San Francisco
Cochair, Curing Coma Campaign
Neurocritical Care Society

MATERIALLY DIFFERENT

In "Computers on Wheels?" (*Issues*, Winter 2023), Matthew Eisler makes a significant contribution in understanding the roots of the modern electric vehicle (EV) revolution. He provides many missing details of the thinking behind Tesla's beginnings, especially the ideas for framing automobiles as consumer commodities. More importantly, he highlights the incompleteness of the "computer on wheels" analogy to the bane of legacy automakers and policymakers alike.

As Eisler notes, while electric vehicles and computers are similar in some respects, they "are significantly different in terms of scale, complexity, and, importantly, lifecycle." One such difference is the intense demand EVs place on being able to develop and sustain extremely complex software not only for safety-critical battery management but for the rest of the vehicle's systems. Tesla's organic software-development capability is a critical reason it has been able to forge ahead of legacy automakers in terms of both features and manufacturing costs. While EV batteries contribute to some 35–40% of an EV's manufacturing cost, vehicle development costs attributable to software are rapidly approaching 50%.

Although the amount of software reinforces the analogy of an EV being a computer on wheels, the analogy fails to account for how EVs materially differ from their internal combustion engine counterparts. EVs represent a new class of cyber-physical system, one that dynamically interacts with and affects its environment in novel ways. For instance, EVs with their software-controlled electric motors no longer need physical linkages to steer or apply power—a joystick or another computer will do. With additional devices to sense the outside world along with requisite computing capability, EVs can more easily drive themselves sans human interaction than can combustion-powered vehicles. Tesla realized this early and made creating autonomous driving capability a priority. In developing self-driving, the company further increased its software prowess over legacy automakers.

As Eisler notes, policymakers wholeheartedly embraced EVs, first to fight pollution and later to combat climate change. However, policymakers have also embraced the potential of autonomous-driving EVs and are counting on them to limit individual vehicle ownership, thus reducing traffic congestion and ultimately reducing greenhouse gas emissions by up to 80% by 2050. Even for Tesla, creating fully self-driving vehicles has been much more difficult than it imagined, illustrating the dangers of policymakers adopting nascent technologies as a future given.

This highlights another critical problem that Eisler pinpoints as resulting from policymakers' embracing EVs as computers on wheels—that of scale. Transitioning to EVs at scale not only demands radical transformations in automakers' global logistical supply chains but also establishes new interdependencies on systems and their capabilities outside their control, from lithium mines to the electrical grid. The grid, for example, will need increased energy generation capacity as well as a significantly improved software capability to keep local utilities from experiencing blackouts as millions of EVs charge concurrently. Policymakers are only now coming to terms with the plethora of network effects EVs, and their related policies, create.

Eisler clearly underscores the myriad challenges EVs present. How well they will be met is an open question.

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BOUNDARY-PUSHING CITIZEN ENGAGEMENT

In "How Would *You* Defend the Planet from Asteroids?" (*Issues*, Winter 2023), Mahmud Farooque and Jason L. Kessler reflect on the Asteroid Grand Challenge (AGC), a series of public deliberation exercises organized by members of the Expert & Citizen Assessment of Science and Technology (ECAST) network and NASA in 2014. Center stage were the positive impacts that citizen deliberations had on NASA representatives and NASA decisionmaking. However, the authors lament that citizen engagement at the agency similar to the AGC has not happened again. As Kessler points out, while the value of citizen engagement is acknowledged within NASA to this day, the "interstitial tissue that enables it to happen" is lacking.

In response to this replication challenge, Farooque poses an "existential question" specifically to the ECAST network, but one that resonates more broadly for engagement scholar-practitioners: should we continue to pursue experimental engagement from the outside or work to concentrate capacity for engagement within federal agencies? While this "outside" vs. "inside" debate remains perennial for pursuing political change, we suggest that the two strategies must work hand-in-hand. From our perspective, the AGC case study provides a road map for how to embrace the nexus of agency process (inside) and boundary-pushing engagement (outside).

First, crucial partnerships between the inside and outside enable success for citizen deliberations. Professionals such as Kessler search and advocate for opportunities and resources for citizen engagement from the inside of agencies such as NASA. Practitioners such as Farooque transport and translate questions, ideas, and perspectives from the outside that expand the immediate priorities of the agency. For example, although NASA presented only two options to focus citizen debate, Farooque explains that citizen discussions produced additional governance questions and options that broadened the impact of deliberation.

Second, centering citizen deliberations around agency priorities yields important impacts for agency decisionmaking. In the AGC, a planetary defense officer confirmed in Farooque and Kessler's account that an important outcome of the exercise was learning from public perspectives on planetary defense and hearing "how important it was for NASA to be doing it." This social learning was valuable to agency decisionmaking, as experiencing this public support somewhat alleviated NASA's decisionmaking gridlock and "pushed it over the threshold." Citizen deliberations organized from the outside might not gain the internal audience to have such impacts on decisionmaking.

Lastly, interaction between agency representatives and citizens energizes both parties. As one participant reported, the opportunity to interact with NASA representatives "made this session special" for citizen participants. Moreover, interactions could be extended to the outside by inviting agency representatives to participate in external events. Continuous agency exposure to public perspectives could in turn build more support for engagement from the inside.

The AGC's success as institutionalized citizen engagement came from linking the spheres of agency process and boundary pushing engagement. This inside/outside strategy poses more of a model than a dilemma, as such exercises accumulate to build the "interstitial tissue" that could support a more dynamic, continuous, boundary-crossing engagement ecosystem.

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JEAN SHIN, *Freshwater,* 2022.

Mahmud Farooque and Jason L. Kessler's first-person account of how scholars and policymakers worked to integrate public views into NASA's Asteroid Grand Challenge initiative describes the twists and turns involved in deploying a relatively new social science research approach, called participatory technology assessment (pTA), to provide policy-relevant input from members of the public on how NASA should prioritize and implement its approach in designing a planetary defense system.

The article provides many helpful takeaways. One of the most important is that even though there is much talk about the importance of involving the public in discussions about how new technological innovations could impact society, figuring out how to do this in practice remains challenging. The pTA approach—daylong events that combine informational sessions about a cutting-edge area of technology with interactive, facilitated discussions on how these technologies might be best managed—advances a new way of strengthening the link between public engagement and decisionmaking. Over the past decade, the pTA approach has been applied to numerous topic areas, and new efforts are underway as well. This includes a project funded by the Sloan Foundation, led by Farooque at Arizona State University, that will apply the pTA methodology to the issue of how to best manage the societal implications of carbon dioxide removal options—which seek to remove greenhouse gases from the atmosphere—that are in the process of being researched and deployed. This pTA effort heeds the call of two landmark consensus studies from the National Academies that highlight the need for more social science research on the rollout of negative emissions technologies and the ocean's role in carbon dioxide sequestration.

More funders from philanthropy and government need to be willing to support this innovative social science approach and help to scale its application across a wider range of technological domains. As Farooque and Kessler so tellingly describe, it can be difficult for funders to make this leap. Due to unfamiliarity with the process, there is inevitable uncertainty upfront about the value of these pTA sessions. Since funders may not know what to expect from pTA processes, that can lead to caution in deciding to finance these efforts. Additionally, it can be difficult for funders familiar with supporting expert-driven science to adapt their mindsets and recognize that such public deliberation activities generate invaluable insight into the strengths and drawbacks of different technology governance options.

There are ways of overcoming these barriers. First, experiencing pTA sessions first-hand is key to understanding their value. Kessler helpfully reflects on this point, noting that going into the pTA sessions, NASA "didn't really know what would come out of it," but that as the sessions progressed "it was clear the results could exceed even our most optimistic expectations." Second, funders can view pTA as a methodological tool that can complement more typical social science approaches, such as one-on-one interviews, focus groups, and surveys. Unlike individual interviews, the pTA approach benefits from group conversation and interaction. Unlike focus groups, pTA is structured to engage hundreds of participates over multiple dialogue sessions. Unlike surveys, time is taken to inform public participants about a technology's development and lay out available governance options.

This is a period of experimentation for funders of science, with philanthropies and governments trying wholly new forms of allocating resources, from lotteries to grant randomization to entirely new institutional arrangements. Along with experimenting with how scientific research is supported, funders need to be similarly bold and willing to advance new approaches to social science research, which is critical to ensuring that public views are effectively brought into science policy debates.

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Finding the Human in the Node

LISA MARGONELLI

In 1949, in a garage near London, an economics student with a background in electrical engineering named Bill Phillips fashioned a collection of hydraulic pumps and pipes into a model of the United Kingdom’s economy. Seven feet high, five feet wide, and three feet deep, the Phillips machine represented money with colored water. National income flowed from a clear tank at the top through a series of valves that extracted government taxes; diverting some of the stream to government spending and allowing some to trickle toward household expenditures and saving. Before widespread use of electronic computers, the Phillips machine offered a dynamic model of an economy, where tightening the screws of a single variable such as interest rates could change the behavior of the whole.

Prominent faculty at the London School of Economics quickly adopted the machine—not only for its ingeniousness, but also because it made the concepts of Keynesian macroeconomics intuitive. In this, it was particularly valuable for policymaking because it presented a vision of the economy that could be quite literally fine-tuned, via valves and screws, bolstering the idea of “macroeconomist as engineer,” as economic historians Mary Morgan and Marcel Boumans wrote in a 1998 paper.

The Phillips machine never showed, for example, mothers deciding whether they could afford bread for their children—the human aspect of the economy is missing from the model—but Morgan and Boumans point out another oversight: it was later discovered that the engineering on the backside of the machine was far more complex and difficult to restore than the transparent tanks and tubes on the front. Out of sight, an elaborate network of pumps and kludges constructed from Phillips’ tacit knowledge maintained the appearance of the rational, circular flow on the front. Of the dozen or so Phillips machines that have been created, only a few are still in working order—but the idea of macroeconomic policymaking as a type of engineering has stuck.

I thought of the Phillips machine and its circulating flows often as we prepared a series of articles on problems in the global information ecosystem for this issue. The spread of false and harmful information is not new: within decades of the invention of the printing press, anti-Semitic propaganda and misogynist guides to witch hunting appeared in Germany. And, for the last 35 years, the Discovery Channel’s Shark Week has served up an entertaining mixture of science, fable, and conspiracy theory about our cartilaginous companions. But concern about the circulation of false information on social media has intensified with political polarization and the pandemic.

After losing the 2016 presidential election, where online conspiracy theories and malicious rumors were a significant political force for the first time in modern American memory, Hillary Clinton made a speech decrying “the epidemic of malicious fake news and false propaganda that flooded social media over the past year.” A month later, Donald Trump adopted the phrase, telling a CNN reporter, “You’re fake news.” By early 2017, social media expert Claire Wardle was fed up with the term. "I made a rallying cry to stop using *fake news* and instead use *misinformation*, *disinformation*, and *malinformation* under the umbrella term *information disorder*." The terms stuck, although Wardle now regrets the way they focused academic attention on "labeling the dots" rather than seeing the larger pattern they made.

As misinformation and disinformation became an area of academic study, it was often described with a set of familiar metaphors: floods, circulating rumors, rising tides, treacherous sea, deluge, drowning. A complex sociotechnical phenomenon of information sharing came to be described as a hydraulic one: misleading information is seen to flow, like errant colored water, through the world's information networks, memorably characterized by Senator Ted Stevens in 2006 as "a series of tubes." The Phillips machine was long forgotten, but misinformation presented as a problem that could be managed through top-down engineering of the flows—regulating the pipes and valves of social media, fact-checking to identify bad information, and weeding out bad actors. Five years later, it has become clear that these actions have amounted to, well, a drop in a vast and expanding ocean.

Wardle proposes that what is missing from academic models of the information ecosystem is a woman she calls Lynda, a composite of people she has studied who fervently share information online. Lynda does not intend to be malicious; she sees herself as helpful, and so she searches earnestly for authoritative information (sometimes from scientific journals) which she shares in, say, anti-vaccine contexts and forums. "She is strategically choosing information to connect with people and promote a worldview. Her criteria for choosing what to post depends less on whether it makes sense rationally and more about her social identities and affinities." Both researchers and communicators, Wardle argues, need to see beyond the facts and the flows and instead look more comprehensively at how people's need for connection, community, and affirmation motivates them to spread narratives. Engineers may have built the internet's great global series of tubes, but it's now operated partly by the Lyndas, the humans in the nodes of the network.

In their study of how the scientific term *mRNA* became the subject of converging global conspiracy theories between 2020 and 2022, Marc Tuters, Tom Willaert, and Trisha Meyer generated maps of the connections between ideas on Twitter. Their focus is on the nodes where individuals use hashtags to glom the term #mRNA to "Anthony Fauci," to #plandemic, to a superconspiracy theory called "The Great Reset." Although trust in science may be eroded by these conspiratorial conglomerations, the authors caution that Twitter users do not necessarily take the narratives at face value; some may just be "trying on" different ideas and personas, and the platform may even make some people less likely to believe conspiracies.

Once you shift your attention from the global hydraulic model to the motivations of individuals in the network, new potential countermeasures appear. Emma Spiro and Kate Starbird write that research on rumors from the previous century is newly relevant because human beings share rumors as ways to deal with anxiety and uncertainty. For decisionmakers and officials hoping to communicate during a crisis, they say, "recognizing these informational and emotional drivers of rumoring can support more empathetic—and perhaps more effective—interventions."

Human beings are also the focus of educator Kari Kivinen, who describes how Finland responded to Russian disinformation campaigns during the country's 2014 elections by emphasizing fact-checking, before realizing that they needed to focus on how individuals *decide* what information is trustworthy. This led to programs that teach kindergarteners how to think about the motivations behind shared information. Beginning with conversations about how wily foxes in folklore trick people, Finnish kids finish high school with a sophisticated understanding of propaganda, as well as the culture of scientific research. The Finnish education system also invests in teachers—who have master's degrees and are familiar with the conduct of research—as well as the formation of children's identities. "Society must pay at least as much attention to children's minds as to social media algorithms," Kivinen writes.

A complex sociotechnical phenomenon of information sharing came to be described as a hydraulic one: misleading information is seen to flow, like errant colored water, through the world's information networks.

In that vein, National Academy of Sciences president Marcia McNutt and Arizona State University president Michael Crow argue that political leaders and the scientific enterprise have a common interest in building trust in information and science among citizens. They note that Thomas Jefferson worried that citizens would be helpless against abuses of constitutional power if they are, in his words, "not enlightened enough to exercise their control," concluding that "the remedy is not to take it from them, but to inform their discretion by education." McNutt and Crow go on to discuss how institutions of science and education might take up that task.

The Phillips machine and US postwar science policy date from the same era, and both emphasize engineering outcomes from the top. In the case of the latter, this means directing flows of money, training streams of scientific and technical professionals, and generating rising tides of published papers, leading to economic spillovers. However, over the past few years, much more attention has been paid to the back of this science policy model—where pumps and kludges have played a significant role in creating a system reflecting inequalities and geographic concentration that is not as rational, fair, or productive as it could be.

Focusing on the human experience could help address these challenges. Right after World War II, American nurse educators built a science of nursing that distinguished itself from the reductionist model of biomedicine, writes nursing historian Dominique Tobbell. Expanding into a research-driven discipline that emphasized health and prioritized patients as actors shaped the kind of knowledge that nursing produced. At the same time, nursing preserved multiple pathways into the profession, which resulted in a more diverse workforce than other science, technology, engineering, and mathematics (STEM) disciplines. Tobbell sees lessons for the whole enterprise: "The way nurses defined their discipline—toward the agency of the patient—created an important model for focusing STEM disciplines on solving societal problems by understanding society itself."

Similarly, focusing attention on individuals could help foster more productive interdisciplinary research. Annie Patrick, a science, technology, and society scholar, describes her experience as a social scientist brought into a federally funded project to revolutionize engineering education. Patrick did wide-ranging interviews with faculty and students, coming to understand them as diverse individuals within a community where multiple supports were required to graduate each student.

But when the study team moved on, Patrick found herself haunted by her interviews; her training as a nurse had emphasized creating interventions to solve patients' problems. "When I saw something going wrong," she writes, "my every professional instinct was to intervene." Ultimately, trusting her trained instincts, Patrick designed three interventions (a podcast, a seminar, and a white paper) to help the engineering community see itself—and the needs and motivations of its members—more clearly. Interdisciplinarity, in her experience, is not only about bringing together specialties, but encouraging individuals to identify and unleash their own inner interdisciplinarity.

Once you shift your attention from the global hydraulic model to the motivations of individuals in the network, new potential countermeasures appear.

Exploring how individuals use their agency in complex systems could even lead to better practice—and more practitioners—of biosafety. Biosafety officer David Gillum explains how the accumulated tacit knowledge of a few thousand biosafety professionals forms a web of precaution that picks up where the written rules leave off. Understanding that tacit knowledge, and how the community generates it, could lead to better ways to reduce risks in biological research, better training of safety professionals, and even better rules. Building these systems, he argues, requires the active participation of individuals, who develop norms and knowledge that can be lost if not recognized. Or, to quote epistemologist Michael Polanyi: "Into every act of knowing there enters a passionate contribution of the person knowing what is being known, and that this coefficient is no mere imperfection but a vital component of his knowledge."

The "vital component" is always the human aspect: the passionate, weird, creative, and unpredictable dynamics that complicate but also make possible our ongoing efforts to improve the world.

MARCIA MCNUTT AND MICHAEL M. CROW

Enhancing Trust in Science and Democracy in an Age of Misinformation

Thomas Jefferson once observed, "I know of no safe depository of the ultimate powers of the society, but the people themselves." He cautioned that correcting "abuses of constitutional power" may not be possible if the people are "not enlightened enough to exercise their control with a wholesome discretion." However, he concluded, "the remedy is not to take it from them, but to inform their discretion by education."

During the roughly 200 years since Jefferson made those pragmatic observations, science has provided incalculable knowledge and innovative tools that have improved people's lives, permitted the pursuit of the general welfare as articulated in the Constitution, and allowed many citizens to enjoy a bountiful existence. Now the world negotiates the intersection of unprecedented opportunities made possible by technological advances while also confronting the interconnected crises of pandemic, war, and climate change. Meanwhile, the volume, velocity, and reach of unintentional misinformation and deliberate disinformation, enabled by advanced information technologies, are distorting public deliberation and undermining trust in science as well as democracy itself.

The misinformation and disinformation that hamper the public's discretion are not new, but the consequences are becoming increasingly stark. For instance, public understanding of climate policy has been stymied by disinformation that has called into question the scientific consensus about the nature of the threat as well as responses to it, such as transitioning to renewable energy sources. More recently, the explosion of misinformation during the COVID-19 pandemic limited the positive impacts of life-saving vaccines. And the war in Ukraine has confirmed that misinformation and disinformation are now weapons routinely unleashed by autocratic regimes to destabilize democracies.

Although scientists and elected leaders inhabit distinct communities, they are often allied by their professions' commitment to the public interest. At this critical juncture, taking Jefferson's admonition seriously requires that scientists and leaders join forces to inform the public's discretion through improved communication and education. In these efforts, science and democracy have much in common. At the individual level, scientists and elected leaders share the need to earn citizens' trust, work in the best interests of the public, and remain transparent about motives, conflicts of interest, and decisionmaking. When misinformation or disinformation undermine the credibility of scientists and political leaders, public trust is weakened, the progress of science is inhibited, and democracy itself is destabilized.

For science, which focuses on generating knowledge and improving decisionmaking, misinformation scrambles the meaning of knowledge as well as its ability to further the public good. The speed of change in science is increasing, as is the complexity of informing the understanding of citizens; as a result, the norms of previous generations are being eroded. More importantly, poorly informed discretion inhibits the policy processes and investment logics that drive efforts to produce and apply knowledge. Thus, Jefferson's words are as relevant today as when they were written: our democracy needs to address the growing gap between scientific knowledge and public understanding by better informing citizens' discretion for the purpose of building a healthier, more prosperous, and better defended society.

Therefore, we believe the scientific community must more fully embrace its vital role in producing and disseminating knowledge in democratic societies. In *Science in a Democratic Society*, philosopher Philip Kitcher reminds us that "science should be shaped to promote democratic ideals." To produce outcomes that advance the public good, scientists must also assess the moral bases of their pursuits. Although the United States has implemented the democratically driven, publicly engaged, scientific culture that Vannevar Bush outlined in *Science, the Endless Frontier* in 1945, Kitcher's moral message remains relevant to both conducting science and communicating the results to the public, which pays for much of the enterprise of scientific discovery and technological innovation. It's on scientists to articulate the moral and public values of the knowledge that they produce in ways that can be understood by citizens and decisionmakers.

However, by organizing themselves largely into groups that rarely reach beyond their own disciplines and by becoming somewhat disconnected from their fellow citizens and from the values of society, many scientists have become less effective than will be necessary in the future. Scientific culture has often left informing or educating the public to other parties such as science teachers, journalists, storytellers, and filmmakers. Instead, scientists principally share the results of their research within the narrow confines of academic and disciplinary journals.

This general detachment from society exacerbates the disconnect, and ultimately the scientific enterprise fails to recognize that it serves democracy and the public interest. Working in isolation, scientists are less likely to produce the sorts of results that are useful for society. Researchers need to better appreciate their potential to influence and impact the broader society.

Today, science has neglected to help the public understand what motivates researchers. This has led to the myth that scientists succeed by agreeing with the consensus—a false narrative that erodes public trust in science. To the contrary, scientists honor those who overturn reigning paradigms and advance understanding by producing knowledge that extends beyond the consensus. A recent paper on the mathematics of color perception, to name one example, overturned a 100-year-old theory of how the eye distinguishes color. Without an informed perspective about the way science is conducted, citizens are less likely to understand that science is an ongoing continuous process to pioneer better ideas and models of how nature is organized.

This process of constant knowledge generation does not align well with the notion that scientists merely supply "right answers." Since the processes of research are not well understood and remain at best abstract to the public, both scientists and elected representatives are forced to address well-intentioned but misguided questions about whether society has enough or too much science or whether the end of science has been reached. Scientific and educational institutions must always find ways to address these kinds of concerns and help people understand the inner workings of scientific culture and scientific processes.

Although anachronistic attitudes within the scientific community are changing, public communication and education are still considered something of a side hustle, an "unscientific" attempt to gain attention. Carl Sagan was infamously denied scientific recognition because his efforts to communicate complex scientific concepts with the public were unappreciated. Even now, scientists are rarely trained to communicate with and inform nonexperts, and the potential for making mistakes, or even just stating an uncomfortable truth, further discourages them from interacting with the public. Of course, it may be unrealistic to expect that scientists—even those who have been trained to engage with the public—can probe the mysteries of, say, how nano particles behave, *as well as* communicate what their research means for human health within the current polarized media ecosystem. The problems associated with producing effective communication are complex and will require innovative research, tools, and techniques.

Just as scientists and communications professionals must be trained to inform the public, the scientific community needs to apply its innovation skills to create new ways of teaching and learning. Scientific institutions and organizations should take inspiration from the ways that businesses have adjusted to the changing needs and wants of their customers in recent years. In an age of continuously morphing social media, the ways society produces and acquires information are rapidly changing, and the scientific community needs to advance its outdated modes of informing and engaging the public in order to keep up.

Science communication is often siloed when it should instead embrace the professional skills that have been pioneered in publishing, moviemaking, and storytelling. These specialized skills have allowed writers, producers, and editors to remake entire sectors of the entertainment business. For instance, consider how the science fiction writer and physicist Arthur C. Clarke worked with editors, publishers, publicists, screenwriters, and director Stanley Kubrick to develop *2001: A Space Odyssey*. Despite such pioneering exemplars, most scientists and the organizations in which they are embedded do not invest sufficiently in educating the public in comprehensible language and concepts.

Undeniably, some agencies are more effective at communicating with their audiences. Take NASA, for instance, which receives support and investment from a public that finds its space exploration and research compelling. Some of the interest may be attributed to the influence of the *Star Wars* and *Star Trek* franchises, but it is also the result of the agency's deliberate strategy to relate their cutting-edge science to everyday life. NASA has invested heavily in communicating the wonder of space exploration in innovative ways—through traveling exhibits, space-themed LEGO sets, programs that bring schoolchildren's experiments to the International Space Station, and grants that involve local entrepreneurs in solving problems.

The National Academies of Sciences, Engineering, and Medicine (NASEM) has long informed the discretion of citizens and policymakers through reports and consensus studies. But more recently, NASEM has begun exploring new ways to communicate the value of science to all citizens. By choosing to directly collaborate with Hollywood, the Science and Entertainment Exchange has successfully matched filmmakers with scientists to encourage more accurate portrayals of scientists—and science—in film and television.

Since the public had many questions during the COVID-19 pandemic that deserved evidence-based answers, NASEM was able to leverage its Based on Science project to help provide clear, concise answers. Initially launched in partnership with Google, the online project was already using NASEM's community of experts to provide up-to-date information about science and health questions that affect the decisions people make each day. During the pandemic, such questions included whether heating one's skin would kill the coronavirus or whether lemon juice could cure COVID. Few scientists would consider researching or publishing papers to address these questions, but it was clear that unintentional misinformation of this type was harming people. To answer these questions, NASEM paired experts on the relevant subjects with skilled science writers who prepared answers that could be easily understood. As the Omicron variant took hold in late 2021, traffic surged, and Based on Science remains some of NASEM's most engaged content, demonstrating the ongoing demand for reliable information.

Although it is difficult to rise above the noise of the internet and social media, NASEM has found, to its delight, that millions of Americans have downloaded its reports and studies on subjects including K–12 science education, the future of nursing, and the effects of Agent Orange. A 2022 study described readers of NASEM publications as "adults motivated to seek out the most credible sources, engage with challenging material, use it to improve the services they provide, and learn more about the world they live in." Finding new ways to deliver high-quality, evidence-based information to people who want it at the times and places that they need it is a long-term challenge that scientific and educational organizations must take on.

Similarly, Arizona State University (ASU) has found that it needed to rethink the conventional system of education. Accordingly, over the past two decades, ASU has worked to promote broad accessibility to research-grade knowledge production at scales that have significant social impact. As a foundational prototype for the New American University model, ASU demonstrates that research excellence and broad accessibility need not be mutually exclusive. The charter of the university reflects these values by measuring the performance of the organization not by the exclusionary standards of conventional elite colleges and universities but instead by the inclusion of students from the broadest possible demographic and by the success of graduates.

We are aiming to bring not only the best students but also the "C" students into the process of making, using, and owning knowledge. Through innovative pedagogy, technologically enhanced delivery, expanded research initiatives, and service to its local communities, ASU further envisions that research universities will become platforms for universal learning, enabling qualified learners from any socioeconomic demographic or life situation to acquire knowledge and skills that they need to advance their careers or interests. For example, ASU partnered with Dreamscape Immersive in a collaborative venture to produce Dreamscape Learn, which merges advanced pedagogy with the powerful emotional storytelling of the entertainment industry. Dreamscape Learn redesigns how students are taught while eliminating gaps in student learning. Furthermore, ASU is now working with other universities in alliances that will differentially improve the discretion of the public by communicating ethical scientific and democratic values of their research.

Science is the primary activity that has allowed humanity to rise above brute subsistence by, for instance, helping to feed more people without condemning others to starvation. Technological innovation has permitted humans to live longer lives that are less burdened by illness and physical toil. Accordingly, we are deeply distressed to see unintentional misinformation and deliberate disinformation erode public trust in science and democracy, interfering with both institutions' ability to construct a better world.

Although scientists have largely stayed on the sidelines as the complexity of the world advances and the role of science in the transformation of the future becomes ever more important, it is no longer acceptable to remain complacent about communicating the critical role of science. As Jefferson observed, scientists and elected leaders must educate the public so that they can make better-informed decisions. We call on science and the institutions associated with it—colleges and universities, governmental agencies and laboratories, business and industry, and nongovernmental organizations—to take responsibility for valuing and investing in communication and education to inform the "wholesome discretion" of all citizens.

In that spirit, we encourage you to attend or participate in the 2023 Nobel Prize Summit hosted by the National Academy of Sciences on May 24–26, 2023, which will focus attention on how misinformation and disinformation are eroding public trust in science and democracy and on how experts and the public can work together to identify solutions.

Marcia McNutt *is the president of the National Academy of Sciences.* ***Michael M. Crow*** *is the president of Arizona State University.*

FRANK LUCAS

A Next-Generation Strategy for American Science

During my tenure in Congress, where I've represented Oklahoma's third district since 1994, I've had the privilege of serving on three committees and working closely with many more. Of these committees, the House Committee on Science, Space, and Technology does not have the highest profile, but it does have one of the most important portfolios. That's because the work done by this committee goes further than addressing the challenges we face today—it paves the way for our long-term development as a nation.

America's economic strength, national security, and our quality of life all fundamentally depend on our ongoing scientific progress. In fact, more than 60% of America's economic growth in the last century is due to advances in science and technology. US public investment in research and development adds nearly $200 billion in economic value, and basic research in particular increases long-term productivity across multiple industries.

The committee's work this year will center on supporting US scientific progress and combatting threats from the Chinese Communist Party (CCP).

The CCP recognizes that science and technology form the bedrock of America's global leadership and is determined to overtake us in these fields. In recent years, China began investing heavily in R&D. Now they are outpacing us by graduating more science, technology, engineering, and mathematics PhD students and publishing more scientific papers. What's more troubling, however, are the CCP's attempts to steal the results of our R&D through cyberattacks, forced intellectual property transfer, and malign recruitment initiatives such as the Thousand Talents Program, which aims to convince foreign-trained scientists to bring their skills, knowledge, and connections to China.

Should the United States lose its position as the global leader in science and technology, there will be grave consequences for the economy and national security. The House Science Committee is working to ensure that won't happen.

When I became ranking member of this committee in 2019, finding a way to retain global leadership became one of my first tasks. I introduced the Securing American Leadership in Science and Technology Act—comprehensive legislation to double down on US investment in basic research and create a national strategy for scientific development.

With this bill as a blueprint, the committee began to draft bipartisan legislation to advance America's scientific and technological capabilities. There were a number of bumps along the road, but two years later, many of the ideas we first laid out in 2020 were passed into law as part of the CHIPS and Science Act.

When I talk about that bill, I like to point out that while the funding for semiconductor chip production is going to build factories today, it's the "science" portion of the legislation that will be the engine of America's economic development for decades to come.

Through the Artemis missions, my youngest granddaughter is going to see the first woman set foot on the Moon, and my hope is that it will inspire her and her peers to do great things.

Central to all the investments and modernizations in the CHIPS and Science Act was the creation of a National Science and Technology Strategy. Our committee directed the White House Office of Science and Technology Policy to develop a comprehensive strategy for America's scientific and technological development every four years.

The national strategy ensures a comprehensive, whole-of-government approach to R&D, which will improve coordination between federal agencies and provide a more thoughtful approach to prioritizing resources. It will ensure that government time, energy, and funding for federal R&D will be focused on the most important challenges facing the country. And, given the increased funding being allocated to federal R&D, this strategy is necessary to maximize the return on our investments and make good use of taxpayer dollars.

In Congress, we'll be focusing on this strategic approach to supporting American competitiveness. While the committee will approach this challenge in many ways, there are three upcoming areas of policymaking that will be critical to our efforts to strengthen American science: unmanned aerial systems, enhanced weather forecasting, and human space exploration.

One area of technology where America is lagging behind China is in unmanned aerial systems, commonly called drones. A single Chinese firm has 90% of the market in drones used for public safety in the United States, as well as 80% of the recreational market. In 2021, the Department of the Treasury identified the company as tied to the "Chinese military industrial complex." The implications for US privacy and security are staggering. Our committee will be considering legislation that will bolster the domestic drone industry by supporting research, development, deployment, and manufacturing here in the United States.

Another area of focus will be on strengthening the National Oceanic and Atmospheric Administration (NOAA). Created by executive order in 1970, NOAA does important work in a range of areas including weather prediction, remote sensing, and climate monitoring. Despite supporting more than one-third of the US economy, NOAA has never been established in law. It is high time we rectified that. We are drafting legislation that codifies NOAA's critical mission in law and stands it up as an independent agency. It will also promote scientific integrity and critical research within the agency, refocusing work on NOAA's core missions.

Finally, the committee will work to reauthorize NASA this year. The space agency hasn't had a comprehensive authorization bill since 2017. This bill will help to focus NASA's work on critical missions as we enter a new era of space exploration. This includes the Artemis program, which will return humans to the Moon for the first time in 50 years. And this time, we'll do more than just visit—we're going to stay. We'll be building habitats and research stations, and we'll use the Moon as a springboard for crewed missions to Mars.

Space exploration produces valuable knowledge of our universe, but it also has important effects on US international competitiveness. The goal of being the first to establish a presence on the Moon is not about beating other countries for bragging rights—it's about ensuring that humanity's off-world presence is grounded in democratic principles of fairness, openness, and equality. We don't want authoritarian regimes to lead the process of humans colonizing space.

Beyond geopolitical concerns, there are other reasons to make sure the Artemis program is moving along. Space exploration is incredibly complicated, and nearly every step presents new challenges and the need to develop new technologies to address them. Those innovations are crucial to our economic growth—they can be commercialized and adapted to improve manufacturing, health care, and consumer products.

The other reason to return to the Moon is less tangible, but no less important. I have a vivid memory of watching the Moon landing as a 9-year-old boy in Oklahoma. It was inspiring, and it helped me and countless others in my generation see a future filled with new possibilities. Through the Artemis missions, my youngest granddaughter is going to see the first woman set foot on the Moon, and my hope is that it will inspire her and her peers to do great things. If our support of American research and development helps to leave her generation with a better world, filled with new technologies, exciting jobs, a bright future, and an amazing off-world view of the Earth, then I will have done my job as chairman of this committee.

Frank Lucas *(R-OK) is chairman of the US House of Representatives Committee on Space, Science, and Technology.*

GUO-FANG TSENG

When Our Medical Students Learn Anatomy, They See a Person, Not a Specimen

In 1986, a Buddhist nun named Cheng Yen started a hospital in Hualien, a rural, mountainous region in eastern Taiwan, a half-day's journey from population centers like Taipei. A few years later, after launching the Tzu Chi Medical College (now Tzu Chi University's School of Medicine, which is still the only medical school in the region), Dharma Master Cheng Yen persuasively broached what is for many an uncomfortable topic: letting a loved one will their body to science. "At life's end," she said, "turn the useless into great use: donate to medical education."

At the time, medical students in Taiwan dissected unclaimed bodies with no information about who those individuals were. The sole purpose of working on cadavers was to gain knowledge on anatomical structures. But Cheng Yen wanted her students to gain more than that: empathy for people and society. She insisted that dissected bodies be willed to the school with the consent of their families and that the anatomy course build on a philosophy to "ease the soul of the deceased and calm the mind of the surviving family." And so her approach, which grew into the Silent Mentor Program at Tzu Chi University's medical school, embraces the identity of the body donor, emphasizing the humanity of the deceased as a silent teacher and altruistic mentor. The program has also transformed physicians' training in universities in Taiwan, Singapore, China, Malaysia, and beyond.

I have directed the Silent Mentor Program since 1997. In Taiwan, the body of a loved one is seen as belonging to the family, rather than the deceased, and bringing together the family and medical students is deeply meaningful for both. In our classes, medical students, surgical trainees, nurses, and other clinicians learn about anatomy and medical techniques—but they also learn about the body donor's life and desire to contribute. Medical students and clinical trainees meet family members and write poems or letters to their "silent mentors" describing what they are learning. When the course is complete, students place their mentors in coffins and send them for cremation. Then they join the family to honor the cremains.

Popular accounts of the Silent Mentor Program are quick to mention how it has eased shortages of medical cadavers. This is true; just two years after its launch, Tzu Chi University began working with donors and their families to transfer hundreds of donated bodies to longer-established and better-known medical schools in Taiwan, which later developed their own programs. At the University of Singapore, my colleagues tell me, pledges to donate have increased from around 30 to around 5,000 in little more than ten years.

Benefits go far beyond the number of donations, however. There is some evidence that our approach helps medical students quiet the discomfort many of them experience when working with a corpse and enhances their scientific learning. The Silent Mentor Program has been invaluable in training surgeons in minimally invasive laparoscopic techniques, now used for essentially all hysterectomies and gynecological cancer surgeries performed at Tzu Chi. My colleagues report that the program can "reduce stress for teachers and trainees, shorten the learning curve, and increase the safety of patients."

But I think the effects of the program on medical education are much more profound: it enhances the humanity of clinicians and those they serve. I know of no equivalent counterpart in Western medical education that so thoroughly integrates an exploration of the body with an understanding of the individual. The field of medicine exists to take care of people, but the gray and grueling atmosphere medical schools create seems to drive away essential human characteristics that medical professionals need. Several lines of research show that empathy decreases over the course of medical education. And yet it is hugely important to patient care: those who trust their doctors are more likely to divulge pertinent details, and empathy is associated with better patient compliance, recall, and ability to follow recommendations.

The recent explosive growth in biomedicine alongside high-tech imaging and manipulation tools help physicians see patients' tissues and even cells in increasing detail, but these tools further obscure the view of a patient as a whole person. Despite calls to integrate the humanities and bedside skills with medical education, relevant instruction in humanity and compassion is too often kept at the periphery of coursework, squeezed in almost as an afterthought. This dehumanizing atmosphere is perversely at odds with the warm good will of those persons who offer their bodies selflessly to benefit future doctors and their patients; medical education can learn much by taking their silent mentorship seriously.

Stripping identity away

The view of a person as a mere collection of tissues and organs is particularly evident in traditional anatomy programs, like those I trained in. All over the world, cadavers are stripped of their identities in labs. As a master's student at National Taiwan University, I dissected unclaimed, nameless bodies with the sole purpose of gaining anatomical knowledge. Later, when I trained and tutored at US medical schools, I saw much the same thing with formally donated bodies. We never learned their names or anything about their lives—they were reduced to their anatomy.

Meanwhile, the surviving family is, almost without exception, left without any knowledge or say in how their loved one is handled. This is underscored by the admission this year by an American medical school that it would stop accepting bodies into its willed body donor program because it had lost track of dozens of bodies' identities and could not return remains to families as promised.

Western medical schools have defaulted to depersonalized routines and values to deal with human donations. This traditional practice of concealing the identity of the donor argues that anonymity lessens the emotional stress of the anatomy laboratory experience and allows for distance, objectivity, and the learning of basic anatomical facts. It nevertheless removes the person or patient aspect of the body and substitutes that with a cadaver specimen or cadaveric materials. This approach to the use of the donor body appears to be an ethnocentric concern not shared by Asian cultures.

> I know of no equivalent counterpart in Western medical education that so thoroughly integrates an exploration of the body with an understanding of the individual.

And such forced anonymity does not stop the students or educators from having thoughts about and even spiritual connections to the bodies they are working on; I remember similar feelings during my own anatomical training and research at National Taiwan University and University of Wisconsin-Madison. I sometimes wondered about the life of the person that I was dissecting and how his body became my learning material.

Medical students are forced to detach their feelings from the body lying on the table. Anatomy labs, and medical education more generally, end up unwittingly teaching a kind of emotional compartmentalization. Consequently, busy clinicians think about organs before the whole body, the living person, or loving family; the health care they provide becomes a series of biomedical measures to rectify an abnormality. To families suffering loss, grief, and uncertainty (and who may struggle to afford a clinical visit), modern medicine assumes a ruthless mask, cold and psychologically distant when connection and compassion are most needed.

A donor with a name

In 1995, I was working as an associate professor of anatomy at National Taiwan University (NTU) when Tzu Chi's medical school approached me. I was a logical choice for recruitment. I grew up in Hualien, and Taiwan (like many places) has a long-standing shortage of anatomists. In 1997, I was a jointly appointed professor at both universities. A few years later, I made the unusual decision to quit NTU (giving up a government pension) and move to Hualien to head the Silent Mentor Program in gross anatomy. We subsequently added a program for surgical training. We now run eight surgical silent mentor workshops a year: three for the medical students, postgraduate physicians, and residents within the Tzu Chi hospital system and five for surgeons and other specialists from various clinical societies in Taiwan and internationally.

Our program begins several weeks before trainees come to their dissection or operating tables. First, they travel, sometimes for hours, to meet the donor's family in their home to learn who the person was and what they hoped to give by donating their bodies.

On the day before the first dissection or operation, families are invited to the Tzu Chi medical school for a beginning ceremony. The trainees assigned to each table share what they've learned about their silent mentor's life to other students, faculty, family, and volunteers. After that, families walk in rows into the dissection or operation room to tables marked with their loved one's name and photograph. Students and family stand side-by-side to remove the blessing sheet covering the face of the body donor. There are often tears from both groups.

Before each session starts, trainees stand by the table and maintain a reverent silence for one minute, practicing contemplation and thanking their mentors. At the end, trainees bow to their mentors to honor them and express gratitude. In the course of their work, students never refer to cadavers or corpses, instead describing them as mentors, or with their name.

At the end of the semester, the gross anatomy dissection students reshape their silent mentor's body by placing all the organs and tissues back in their original positions and suture the skin stitch by stitch. This simple courtesy may seem excessive, but it allows the body to be returned whole, reassuring the family that their loved one has been treated with respect. Students wrap the bodies in gauze and dress them in formal clothes. The families then join the students to place the silent mentors in caskets, along with letters, poems, and other remembrances the students have written. Walking together, students and family send the coffins to the local crematorium and then gather for a gratitude ceremony that includes recapping the life history of each mentor. The families do not walk into the large university rooms as strangers; our students find them and greet them. I have seen decades-long friendships develop between students and their silent mentors' families.

For the family, we hope the transparency, participation, and interaction in the program helps the survivors gain inner peace and ease their grieving. And family members often tell us that it does serve this purpose. In recent years, several women whose husbands had been silent mentors opted to become mentors themselves upon their death, as did the daughter of a man who had been one of our earliest silent mentors.

Students consistently report that their interactions with families increase their motivation to learn in their class. So does hearing directly from family members about their loved one's wishes. One woman, whose husband died unexpectedly at 52, told students, "I would rather have you make 20 practice cuts on my husband than to see you make any mistake on patients." A 2016 survey of surgical trainees in the Silent Mentor Program reported that all found it "meaningful" or "very meaningful." Both students and family members see conducting dissections as carrying out the deceased's will.

The Silent Mentor Program grew out of a Buddhist tradition, but the values of compassion and respect are not exclusive to Buddhism. Malaya University in Malaysia, for example, has worked with silent mentors and families who followed Catholicism and other Christian denominations as well as Hinduism and other religions. Medical schools in Singapore and Malaysia have adopted the program in full. Schools in countries such as China and Thailand have adopted crucial pieces of the program, including the gratitude ceremonies where family members participate and donors are thanked by name.

The silent mentor concept elevates anatomy by properly contextualizing the human body—and medicine—within families, society, and our mutual interdependencies.

All these humanistic interactions are time-consuming and require tedious planning. Perhaps it seems impractical, even wasteful, to those considering the discipline of anatomy alone, itself often considered only a small corner of medical education. But the silent mentor concept elevates anatomy by properly contextualizing the human body—and medicine—within families, society, and our mutual interdependencies. Incorporating the humanity of body donors through students' interaction with their families is like a renaissance in anatomy teaching.

I have taught anatomy for 40 years, and, although I am not religious, I believe the gratitude, respect, and love the program promotes is both the essence of health care and of life itself. For my last lectures, I will lie down.

***Guo-Fang Tseng** is a professor of anatomy and director of the Silent Mentor Program at Tzu Chi University in Taiwan.*

Interview

"If we are simply creating techies who can only work with the technology, we're in big trouble."

Illustration by Shonagh Rae

Freeman A. Hrabowski III is a luminary in the world of higher education. While transforming a regional commuter school into a research powerhouse, he led pathbreaking initiatives to make scientific and technical disciplines more diverse.

Mathematician and educator Freeman A. Hrabowski III has led groundbreaking efforts to increase diversity in science, technology, engineering, and mathematics (STEM) fields throughout his career. As president of the University of Maryland, Baltimore County (UMBC) for three decades, Hrabowski transformed a regional commuter school into a top-tier research university. For more than 15 years, UMBC has been the top US producer of Black undergraduates who continue on to receive PhDs in the natural sciences and engineering.

The Howard Hughes Medical Institute recently launched the Freeman Hrabowski Scholars Program, a $1.5 billion initiative that aims to advance diversity in the sciences. And in May 2023, Hrabowski will receive the National Academy of Sciences' Public Welfare Medal, which is presented annually to honor extraordinary use of science for the public good.

Issues editor Sara Frueh spoke with Hrabowski to get his insights on the importance of the humanities, culture change at universities, and scientists' involvement in civic life.

When you think about the workforce America will need in the future, what does our education system need to do differently and better than it's doing now?

Hrabowski: Starting with pre-K through higher ed, we need to be thinking about how our curriculum addresses connections across disciplines while thinking about ways to include more people in those discussions.

I'm a strong believer in the need to rethink who can do what well. We have this way of bifurcating people into two groups: we still tell children that people are either good in math and science or they're good in English and the arts. We need to start believing that we can teach students to build their skills and become even more interested in both areas.

This is important when thinking about the workforce. More and more, we need people who are experts in STEM and also have grounding in the humanities. If we are simply creating techies who can only work with the technology, we're in big trouble. We need people who can think about the increasingly important role of technology and look at the big ethical and philosophical questions that we'll be facing as we go through this next period in our development as a society.

A little over a decade ago you were head of a National Academies study that offered recommendations for increasing the participation and success of students of color in STEM. Where are we with that now?

Hrabowski: In 2021, my advisor Peter Henderson and I wrote an article for *Issues* saying that we'd only moved from 2.2% of the PhDs going to African Americans to 2.3%. So in that sense, we don't see progress.

We still have big challenges with bringing women into computing areas especially, we know that. But I do see progress through the ADVANCE program from the National Science Foundation, where institutions are encouraged to work on culture change that will lead to more women not only being recruited to the faculty, but also getting tenure and moving into administrative positions.

I have several examples of hope through major initiatives in the scientific community. The National Institutes of Health (NIH) has created a program to give grants to institutions that are proposing to increase diversity in the faculty—very much like the new Howard Hughes Medical Institute program in my name, which looks at ways of encouraging outstanding early-career faculty members to build diverse labs.

We also have a major challenge in that many more people of all races who start in STEM leave it within the first two years. I often ask audiences, "How many of you started off in premed and science or engineering, and became lawyers?" And you'd be amazed at the number of people who raise their hands.

The point is that in many places, we still think of the first year or two of science and engineering as weed-out courses. There are institutions working to change that, but we don't even expect most students who begin with STEM majors to succeed in those courses.

So I would say we still have a long way to go. And we have a lot of work to do in thinking about culture change.

In your writing, you've described changing an institution's culture as "hard as hell." This year's report on racism in STEM from the National Academies of Sciences, Engineering, and Medicine pointed to the need for culture change to increase diversity, equity, and inclusion. So if an institution or university wants to start to shift its culture to be more inclusive, how does it begin?

Hrabowski: We first have to have some understanding of that word "culture." Writer Eric Weiner says, "Culture is the sea we swim in—so pervasive, so all-consuming, that we fail to notice its existence until we step out of it." It's the assumptions we make. It's the incentives that we give for certain kinds of behavior. It's in the questions we ask and the ones we don't ask.

To change the culture, we must be empowered to look in the mirror and to be honest with ourselves first—to have the difficult conversations about what we do well, but also what are we not doing well.

I'll give you just one example of a need for culture change in our society. With the exception of the most prestigious institutions and the largest and richest public universities, when you look across the two-year institutions, most publics, and some private universities, what you will see across races is that the majority have six-year graduation rates well below 50%, often around 30-something percent. And that's not just for minorities, that's in general. A large portion of our population may start college, but they never graduate. Now, why is that important? And what does that have to do with culture change?

One of the reasons students at two-year institutions and many publics don't make it past the first year is that they don't do well in lower-level mathematics. If we look at every institution, we will see that many are still teaching that math course the way they did 50 years ago. There's a need for the difficult conversation. What we did at UMBC was to have those difficult conversations, and faculty wanted to work on course redesign—and to rethink, for example, first-year chemistry. They gave it more than just a lecture approach, and used collaborative learning, active learning, professional development, use of technology, real-time assessments, and group work.

It is in that collaboration and the group work and the asking of questions and the feeding off of each other that we solve problems. But too often we tend to teach in a way that says, "If somebody worked with somebody else, that's cheating in class." We do that from pre-K onward. And yet, if you look at how science problems are solved, or if you look at our human problems to solve, it's never just with one person.

I want to talk a little bit more about the difficult conversations piece. You've written that a healthy campus is one where those difficult conversations can happen. How can educators equip their students to have productive conversations as they head out into a contentious and divided society?

Hrabowski**:** All of us criticize elected officials, and we tend to criticize Congress for what it doesn't get done. Now, all those members of Congress—almost all—are graduates of our institutions of higher education, and yet many are not willing, it seems, to open their minds and learn how to agree to disagree and seek the truth.

Leaders of institutions need to take responsibility for attempting to create a culture, a climate, that encourages people to come to the table and talk about the difficult issues and to say what they really think without being attacked.

I would argue that too often we teach the importance of winning. Fred Lawrence, secretary of Phi Beta Kappa, talks about the importance of teaching students to be able to present their arguments and back up the arguments with evidence—but also to have the willingness to listen to others who think differently, and to look for the evidence in what they say. And then having the wisdom to seek the common ground as we seek the truth.

I was always saying to students, "Don't let someone make you angry. When you don't agree, simply breathe deeply, and give yourself time to think about it. Then see if you can put yourself in the shoes of the other person: Why'd that person say that? What can you learn from what the person said, whether you like it or not?" What we are talking about is learning how to build trust. And through our expectations, to help people know what's important on campus.

In spite of the progress we've made in desegregating our higher education institutions, we still have, in some ways, hypersegregation in that every group keeps to itself. And while I understand the strength in people of any group with something in common coming together—women, LGBTQ students, Asian and Black and Hispanic groups—and in having time to celebrate commonality, I question the lack of proactive approaches to ensure students get to know people very different from themselves—not just in the classroom, but on campus.

The question I ask as we in the scientific community and higher education look in the mirror is: Are we intentional about ensuring that people who enter the institution will necessarily get to know people different from themselves? To have the substantive conversations with people different from themselves? When do we have those conversations about disagreements and different perspectives? If we don't learn to do it in universities, when would we ever learn to do it?

What problem or question—in education or beyond—are you most interested in now?

Hrabowski**:** One is a broad question about education: What would it take to create a society in which the vast majority of children of any race can read and think well? Because if you give me a child who can read well, I can teach her to solve math word problems. A large proportion of the children in our country are not literate when they graduate from high school, let alone from the eighth grade. And a larger percentage of those are children of color, and clearly a large percentage of those are from low-income backgrounds. That's a fundamental question that I'm working on—pre-K through twelfth grade.

And then more specifically, the question for me is: What is it going to take to create a professoriate that will make exceptional achievement in STEM by people of color the rule rather than the exception?

While I'm a strong believer in finding talent from all over the world and attracting people to the United States, I also want to see us doing what we can to build the talent that is from here. We need both.

> "We need people who can think about the increasingly important role of technology and look at the big ethical and philosophical questions that we'll be facing as we go through this next period in our development as a society."

You were involved in the Children's March in Birmingham in 1963, and I'm wondering what insights your early experience with the civil rights movement gave you about the possibility and difficulty of society-wide change?

Hrabowski: That story starts with me sitting in the back of church and doing my algebra word problems. I'm 12 years old, and I was listening to Dr. King, and he said, "If the children participate in this peaceful protest, all of America will know that even our young people know the difference between right and wrong, and they want a better education."

And for me, I was so excited because it meant I might be able to go to the white schools. We had some great Black teachers, but there were so many messages to us in the quality of the physical facilities and the resources that our teachers had; the white schools had the new books while we got hand-me-down books. I had never previously thought about the possibility of going to a white school because the one time after the 1954 Supreme Court decision that some Black children tried to integrate one of our schools, good Christian people threw rocks at their heads.

And by 1963, I still thought it just wouldn't happen. So when Dr. King said it could happen, it was the first time that I thought, "Well, maybe something could change." That was the message—that maybe something can change—but I can't sit on the sidelines. I've got to be a part of it. And the lesson for me was that we must empower children to believe they can help bring about change—and the way they can do it is by being their best.

I will say this: being in jail was horrific. We were treated like animals, like slaves. Not enough bathrooms. There were children much younger than me. And yet, somehow, the message from our parents and from Dr. King and his leaders was, "We're not animals, we're not slaves. We cannot allow anyone else to define who we are."

The message from the civil rights movement is that we cannot give up. We can keep moving forward—it's up to us. And that's also true in terms of making science more inclusive and more representative. We went through a period during the COVID pandemic when the light was shining on the lack of trust that people of color and others have for science and medicine. This had been quietly known, but COVID really shone a light on it. And that was when the notion that we have to build trust became so real.

One of my ways of building trust was to say, "My wife and I are in this study, and we are doing okay. We've had the vaccine." But secondly, I would point to this Black woman, Kizzmekia Corbett, who was leading a research team—and who is also a UMBC alumna. When I could tell African Americans that one of the leaders of the team at NIH who developed the Moderna vaccine was a Black woman—at first, they wouldn't believe me.

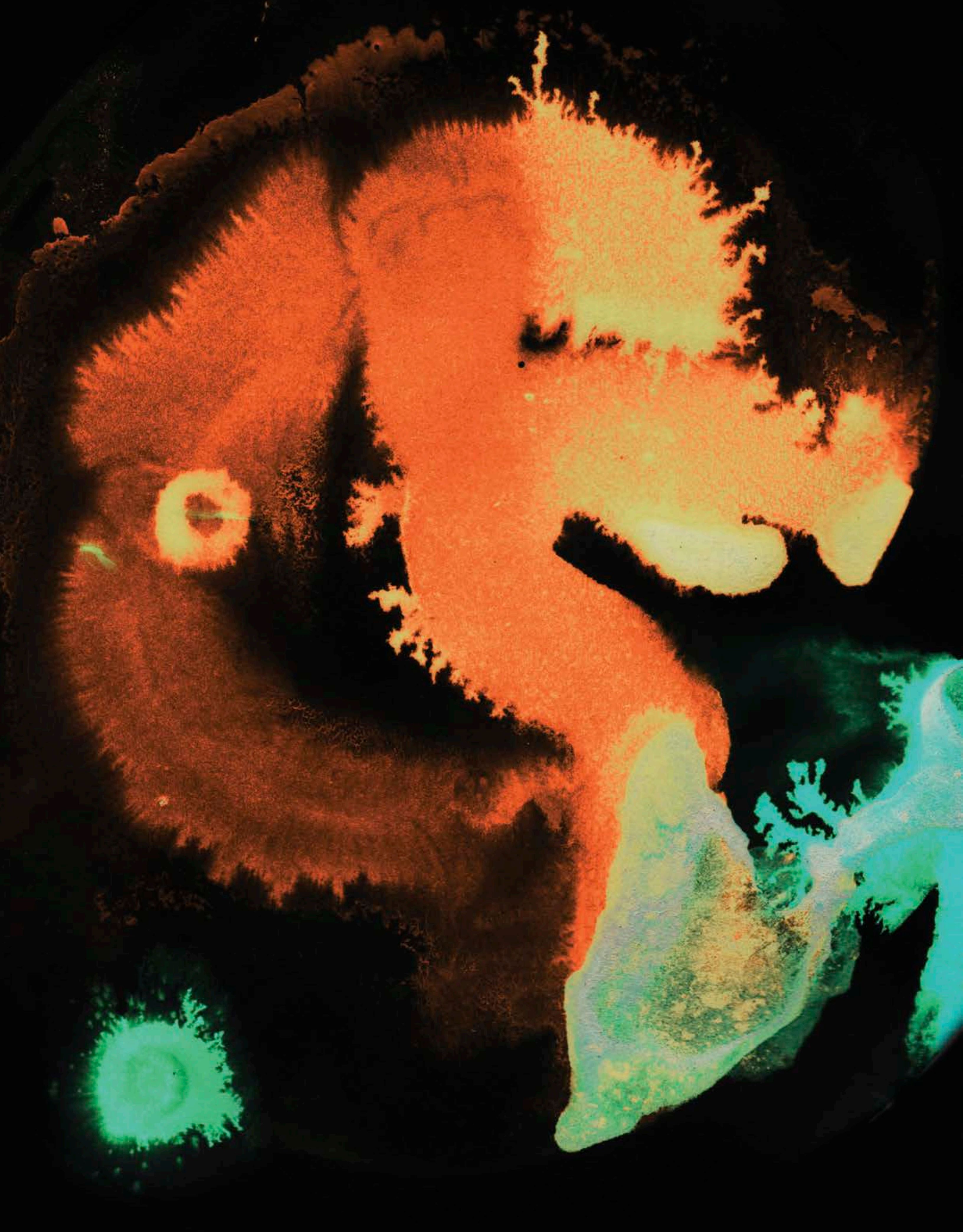
But this fact does several things. It says to little girls of any race, "Wow. I maybe could do that." It says to people of color, "Maybe I can trust the science, because people looking like me are helping to develop it." Of all the messages, it's that message about representation—that when people see people like themselves helping to solve the problems, they begin to believe in the value of those solutions.

In the middle of all the challenges that our country is facing—including political polarization, threats to democracy, racism, and divisions over how to address it—what gives you hope?

Hrabowski: History gives me hope. When I see the challenges that we face, and the need to talk about anti-racism or about how women are being treated in the wrong way, the first thought I have is, "Yeah. But we were having those problems, and we fought, and we moved to another level." And I'm saying, "We can do it again." It's that notion that we make some progress, we move backwards, and then we've got to push forward.

But the other thing that gives me hope is my students and my graduates. They are so excited about the work that they do. Whether they are in the life sciences or in computer science or whatever the area, they're so excited about changing the world. This is what's so exciting about young people. They sometimes don't know what they don't know or what the barrier is. And I see my students knocking down barriers as if it's no big deal.

I am so excited about that progress and their understanding that as scientists, as researchers, they must also be involved in civic life. As scientists and researchers, we must understand that unless we can be involved in the democratic process, we can't accomplish what we want to accomplish. We need to understand the importance of finding common ground. That gives me hope.



TRACY K. SMITH

My God, It's Full of Stars (Part 5)

When my father worked on the Hubble Telescope, he said
They operated like surgeons: scrubbed and sheathed
In papery green, the room a clean cold, a bright white.

He'd read Larry Niven at home, and drink scotch on the rocks,
His eyes exhausted and pink. These were the Reagan years,
When we lived with our finger on The Button and struggled

To view our enemies as children. My father spent whole seasons
Bowing before the oracle-eye, hungry for what it would find.
His face lit-up whenever anyone asked, and his arms would rise

As if he were weightless, perfectly at ease in the never-ending
Night of space. On the ground, we tied postcards to balloons
For peace. Prince Charles married Lady Di. Rock Hudson Died.

We learned new words for things. The decade changed.

The first few pictures came back blurred, and I felt ashamed
For all the cheerful engineers, my father and his tribe. The second time,
The optics jibed. We saw to the edge of all there is—

So brutal and alive it seemed to comprehend us back.

Tracy K. Smith *is a professor of English and of African and African-American studies at Harvard University. She is the author of five books of poetry and a memoir. Her father worked as an engineer on the Hubble Space Telescope in the early 1980s.*

This poem is featured in the Poets for Science *exhibit created by the Wick Poetry Center at Kent State University and poet Jane Hirshfield. Opening in April to coincide with National Poetry Month, the exhibit is on view through September 8, 2023, at the National Academy of Sciences in Washington, DC.*

Credit: Tracy K. Smith, "My God, It's Full of Stars (Part 5)" from *Such Color: New and Selected Poems.* Copyright © 2011 by Tracy K. Smith. Reprinted with the permission of The Permissions Company, LLC on behalf of Graywolf Press, Minneapolis, Minnesota, www.graywolfpress.org.

Illustration by Shonagh Rae

How Science Gets Drawn Into Global Conspiracy Narratives

MARC TUTERS, TOM WILLAERT, AND TRISHA MEYER

A few short years ago, mRNA (messenger ribonucleic acid) was the subject of fundamental research, but it is now known as the basis for COVID-19 vaccines. At the same time, the concept has become linked—particularly on social media—to global conspiracy theories attributing nefarious motives to people associated with science. How did this happen?

In our work, we use social media data to track evolving narratives empirically. By analyzing the terms that have become associated with mRNA on Twitter since early 2020, we have gained insight into how seemingly innocuous scientific concepts acquire sinister connotations through association. Understanding how this process occurs can be helpful in determining which countermeasures might be effective.

Hashtags are key to this analysis. Used to cross-link social media posts, hashtags generally consist of a word preceded by a pound symbol: #mRNA, for example. Hashtags make such concepts easier to find because they can be easily searched. By observing how hashtags co-occur over time, we learn how ideas are linked to each other on social media. This approach is useful for understanding the ways in which disparate concepts become related to evolving narratives.

To find out how the term *mRNA* became connected to far-flung conspiracy theories, we collected a sample of 87,000 tweets containing the hashtag #mRNA over the three-year period from early 2020 to the end of 2022. This allowed us to look at how mRNA was juxtaposed with other ideas on social media over that time. Our analysis looks at time continuously, but we've found it helpful to take "slices" from the dataset to highlight the way the narrative took shape and then shifted over time.

We looked at where #mRNA occurred next to other hashtags, which gives a sense of how the term became connected to other ideas. We presented this data visually, displaying the connections as a network where each node represents a different hashtag and each edge represents the number of times two hashtags co-occur in our dataset. Starting with tweets using the hashtag #mRNA, this method allows us to see how sometimes unexpected semantic networks of associations can develop around ideas. Although co-occurring hashtags should not be taken as representing general discussions about mRNA, their changing patterns over time may offer insights into how issues may be hijacked and misinformation spread.

In our first sample, from early 2020, the hashtags co-occurring with #mRNA were largely scientific or financial, reflecting prepandemic views. To make this network graph more readable, we "cleaned" the data, systematically removing all hashtag nodes above and below certain thresholds determined by number of connections. The distance between nodes indicates how often terms are used together in posts, and the size of the text reflects the sum of its connections. Thus, larger text shows terms that are highly interconnected. The color coding reflects which communities are involved, which is discovered through an automated process that examines connections. The first figure depicts a mostly pale green community made up of hashtags corresponding to scientific terms as well as a gray colored community devoted to discussing biotech investment.

These figures make it possible to examine how the narrative around mRNA evolved over time. As vaccines went into production, new semantic networks associated with the term quickly began to develop. One cannot simply assume this method represents all the opinions that are "out there" in society, but it can nevertheless be quite helpful in understanding how dramatic conspiracy narratives attach themselves to aspects of science and technology.

In December 2020, around when Pfizer's COVID-19 vaccine was given an emergency use authorization for widespread use, the term *mRNA* started to be associated with resistance to vaccines. By early 2021, the hashtag #mRNA started to be combined in Germany with other hashtags that reference concerns responding to "compulsory vaccination" (#impfplicht), with charges of "crimes against humanity" and calls for a "Nuremberg 2."

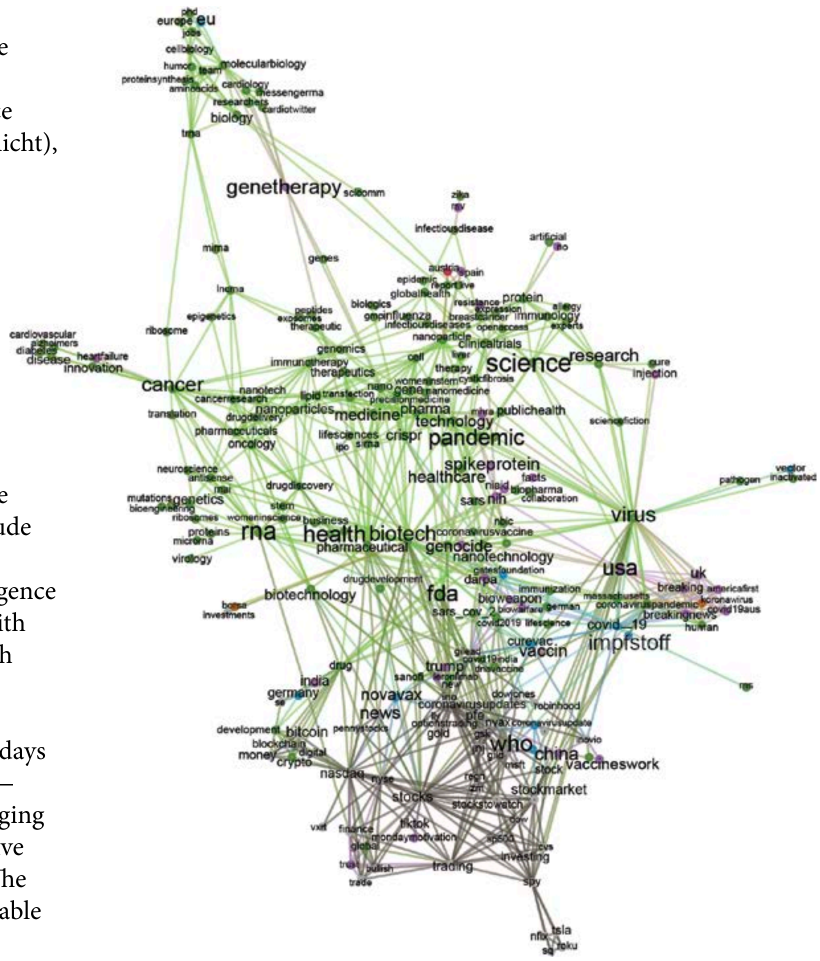
In Figure 2, you can see a blue community representing German hashtags that were not present the year before. These hashtags reflect language used in the anti-lockdown protests that were taking place in Germany at the time. The protests represented a wide range of ideologies, blending right-wing populism, left-wing libertarianism, and alternative health advocacy—the so-called lateral thinkers or *Querdenker* movement.

In addition to the large German community, you can see much smaller national grey and red communities that include hashtags connected to the anti-lockdown protests in the Netherlands and Italy, respectively. Also visible is the emergence of another large English-language community in purple, with hashtags in English referring to people and institutions such as Anthony Fauci and the Centers for Disease Control and Prevention, as well as #plandemic and #covid1984.

This visualization also provides a glimpse into the early days of the conspiracy that came to be called "The Great Reset"—through the hashtags #greatreset and #WEF. This wide-ranging and convoluted conspiracy concerns an eponymous initiative launched by the World Economic Forum (WEF) in 2020. The WEF's Great Reset sought to promote a vision for a sustainable postpandemic world rooted in "a new social contract that honors the dignity of every human being." Coming at a moment of rising populist sentiment, the WEF's vague yet ambitious Great Reset plan fed directly into existing fears about craven "globalist" elites undermining both national sovereignty and "individual sovereignty," a political stance that motivated many anti-vaccine activists. In late 2020, around the time of the US presidential election, the Great Reset conspiracy theory began trending globally on Twitter after being boosted by right-wing influencers in the United States and Europe. As our research demonstrates, the conspiracy continues to proliferate.

The narrative at the core of the Great Reset conspiracy is a dystopian fantasy of global control being imposed on the world's population by the economic elite, including figures such as Bill Gates, who typically attend the WEF's yearly conferences in Davos, Switzerland. According to this narrative, mRNA-based vaccines should be perceived as an instrument by which these elites can implement a single world government. One feature of the Great Reset conspiracy theory on Twitter is how it takes over hashtags and redefines them. Just as the WEF lost control over the messaging around their own initiative, so too has the

Figure 1: **EARLY 2020 #MRNA CO-HASHTAG NETWORK IN TWITTER**

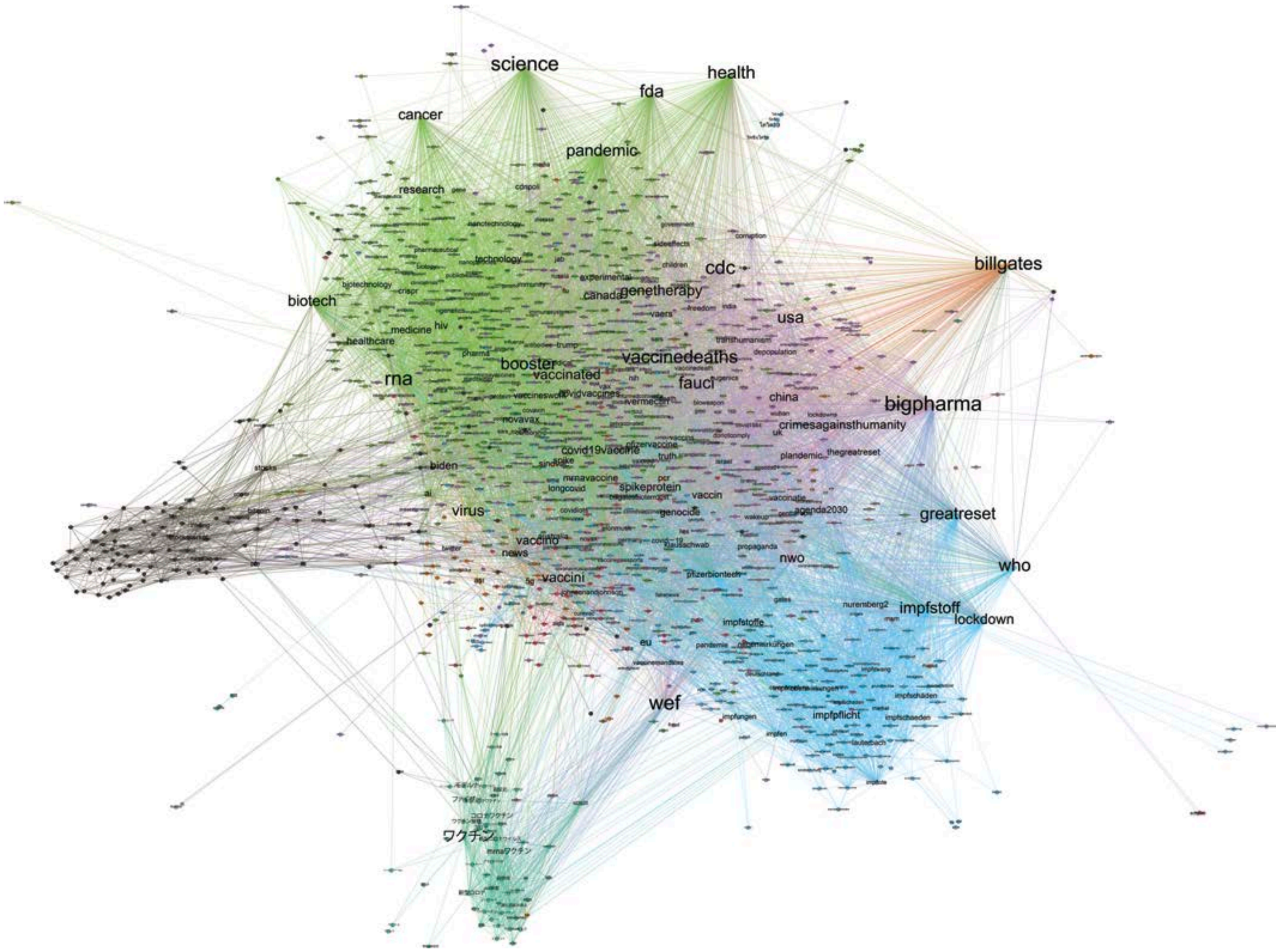


conspiracy narrative attached itself to and redefined numerous other discussions on the platform—notably, discussions around #mRNA.

By the end of 2022, the Great Reset conspiracy narrative had come to eclipse the scientific and economic associations of the #mRNA in our dataset. In Figure 3, you can also see that the purple community has many more references to frightening health concerns, most notably "vaccine death," as well as references to the New World Order (#nwo) conspiracy theory, which can be traced back to far-right movements from the 1960s.

In addition to national communities, the visualization shows new communities, including a Japanese one in darker green expressing concerns about "depopulation" (#人口削減) and a Turkish one in orange expressing concerns about "vaccine victims" (#aşımağdurları). Around the perimeter you can also see large and highly connected terms shared by all of these communities, including *Great Reset*, *Bill Gates*, *WEF*, and *vaccine injuries*.

Figure 2: **EARLY 2021 #MRNA CO-HASHTAG NETWORK IN TWITTER**



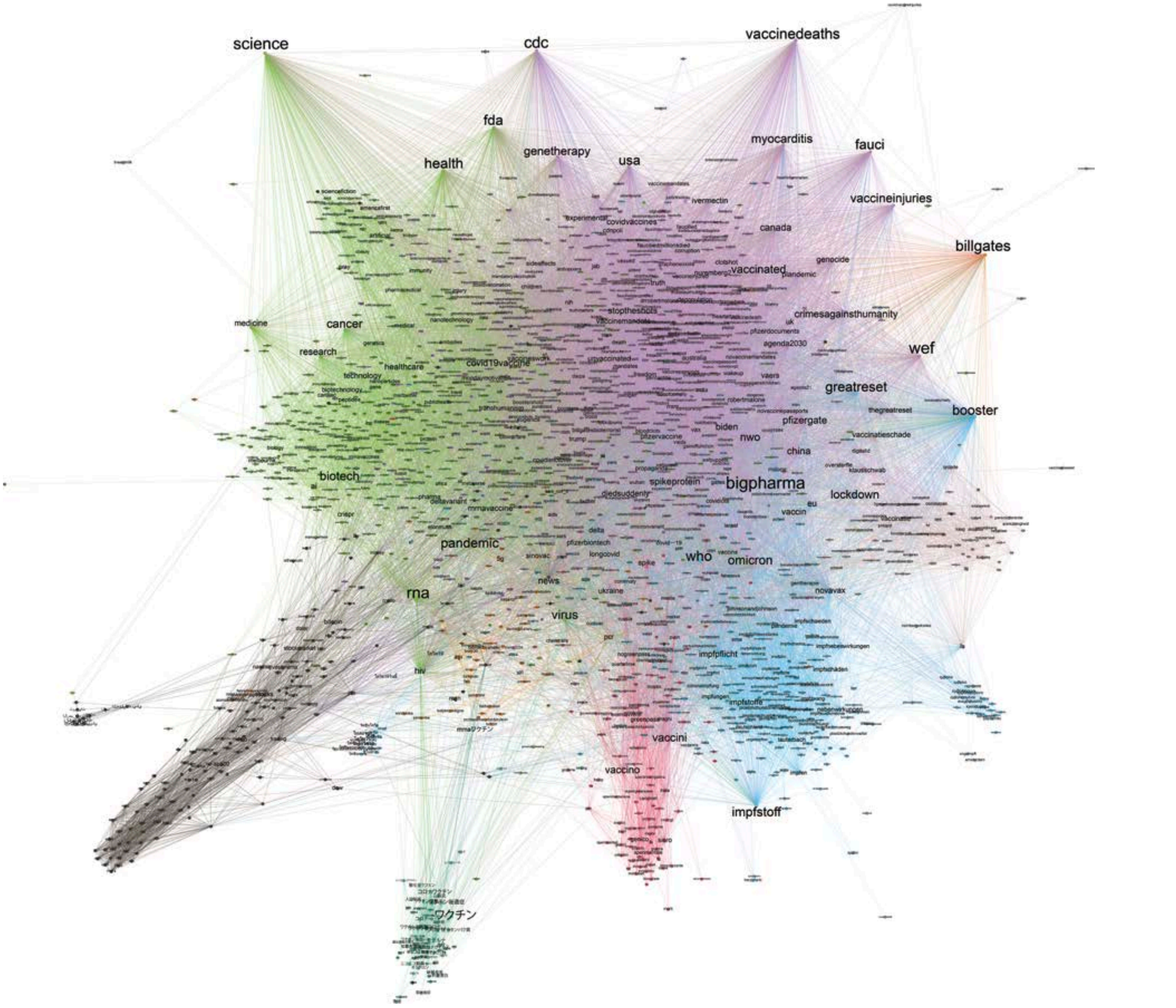
The co-hashtag networks that have attached themselves to #mRNA in the last few years illustrate how scientists, scientific concepts, emerging technologies, and research institutions are appropriated and redefined as actors within the scripts of conspiracy theories. Notable examples include Bill Gates, who figures prominently alongside career scientist and policy advisor Anthony Fauci—both of whom are often presented as antagonists in the conspiracy narrative around mRNA.

Evolving semantic associations like these may be understood as reflecting how the concept of mRNA became entangled with reactionary narratives that channeled fear and uncertainty about scientific innovations. Even more of this is evident today, in early 2023. With Twitter's content moderation significantly enfeebled, #mRNA is merely one of many entry points into a vortex of conspiracies swirling around other science and technology hashtags, including #DigitalId and #SmartCities. Over time, these conversations become ever more semantically interconnected, mirroring a defining feature of conspiracy theories themselves—that "everything is connected."

Like many forms of narrative, conspiracy theories include networks of relations between characters, concepts, and other relevant entities like institutions or agencies. A common feature of conspiracy theories is the way that apparently unrelated concepts are pulled into seemingly coherent structures of associations. These associations may then combine into new, overarching narratives. During the pandemic, commentators began observing an intensified convergence of conspiracy narratives into what political scientist Michael Barkun refers to as "superconspiracies."

Although the dynamic of narrative convergence is not unique to social media, there has been speculation that social media platforms may accelerate the process. For example, automated content recommendation on platforms like YouTube may draw users into rabbit holes of ever more extreme narratives. But differences between platforms also matter—disinformation and conspiracy theories evolve more rapidly on some platforms than

Figure 3: **EARLY 2022 #MRNA CO-HASHTAG NETWORK IN TWITTER**



All figures have been filtered for readability by removing the top 18 and bottom 100 nodes by weighted degree, with text sized by weighted degree, and color generated by modularity class. The complete dataset 2020–2023 contains 87,000 tweets.

on others. This can be attributed to design features of platforms that determine how things can be said, as well as to community standards, which are the terms and conditions governing what can be said.

On different social media platforms, users have a wide range of options—typically referred to as "affordances"—to actively connect narratives across communities and sources. For example, Twitter allows users to refer to multiple different entities in a single tweet, show them together in other images or videos accompanying the tweet, or tie them together through hyperlinks to external sources. Twitter and some other platforms allow users to tag their posts with hashtags to make them more searchable. Social media is, in this sense, uniquely suited to enable the sort of interconnected narrative- and network-building that can be seen in conspiracy theories.

In our research, we've uncovered dense networks of associations where users have added multiple hashtags to their posts, a practice called "hashtag-stuffing." We speculate that posters do this in the hopes of giving their posts higher degrees of visibility or retrievability. In extreme cases, which we have previously documented on Instagram, posts can include dozens of hashtags that are seemingly unrelated to each other or to the actual content of the post they accompany. In this process, references to previously distinct narratives are brought together, intensifying the process of narrative convergence. Although the users' intention is probably to attract a slightly larger audience—and sometimes to make a quick buck—over time, we believe the effect may be to draw communities more tightly together, clustering around shared antagonism and antipathy.

This dynamic helps explain how conspiratorial keywords like #crimesagainsthumanity and #vaccinedeath glom onto seemingly neutral terms like #mRNA. What's more, this process of glomming seems to occur all over Twitter at the moment—so that if we started from a completely different and seemingly unrelated hashtag (#transhumanism or #FourthIndustrialRevolution, for example), we might have encountered much the same pattern, with those other hashtags becoming increasingly connected to the same "Great Reset" narrative emerging over time.

While this phenomenon of conspiracy narrative convergence appears very concerning, it does not necessarily reflect users' actual convictions. Twitter users do not necessarily take these narratives at face value. In fact, some researchers have claimed that paradoxically, unlike other major platforms, Twitter may actually have a "negative effect on conspiracy beliefs." Though in some cases users may really believe in these narratives, in others it could be that they're merely "trying on" different ideas. Sociologist Aris Komporozos-Athanasiou refers to this use of social media as "speculative communities" built on an ambivalent form of belonging. Finally, because active Twitter users represent a relatively small section of the population, our findings should not be taken as somehow representing broad general tendencies.

What our methods do reveal is that Twitter's affordances appear to enable the building and spread of conspiratorial narratives and their insinuation into discussions on all kinds of seemingly unrelated topics. This is a significant matter of concern when it comes to public understanding of science and technology: the unchecked spread of these conspiratorial narratives could severely undermine the networks of trust on which society is built.

The mechanisms that we have uncovered here have implications for policies and strategies that combat misinformation and disinformation, which currently do not take the convergence of social media affordances and the narrative structure of conspiracy theories into account. The first step (as in many misinformation-countering strategies) is to consider changing platform governance. In addition to different affordances, platforms have various guidelines that set acceptable speech and define rules on what is considered illegal, harmful, or antagonizing content. As of March 2023, Twitter's guidelines aim to restrict "violence, harassment, and other similar types of behavior," as these might "discourage people from expressing themselves." The platform's rules thereby address, among other things, violence, terrorism, violent extremism, child sexual exploitation, abuse, harassment, hateful conduct, graphic violence, and adult content. But these rules do not address hashtag stuffing or the process that enables disparate ideas and narratives to be easily glommed together in formats that make them more easily searched and shared.

The standard mechanism through which platform rules are enforced is content moderation. Decisions concerning what content is allowed or removed on a platform are a continually negotiated balance among free expression, illegality, harm, and toxicity. On mainstream social media platforms, restrictions on disinformation are often broader than legally necessary (at least in liberal democracies), but controls are typically implemented in an uncoordinated and reactive manner. As a result, emerging alternative platforms such as Telegram, Gab, and TruthSocial, through their promises of lax content moderation, might exert a high degree of attraction for antagonistic actors and narratives that have been deplatformed elsewhere. Whether content moderation ultimately leads to a game of whack-a-mole as users move from platform to platform is an ongoing subject of discussion among researchers in this field.

Our glimpse into the network of associations for the hashtag #mRNA on Twitter reveals the complex dynamics through which science becomes the object of disinformation. Although scientists and others have interpreted these patterns as speaking to the contested nature of science in these networks, our work indicates that social media can create resonances between otherwise disparate issues and that scientific concepts might be roped into conspiracy theories and disinformation—along with everything else. These complex networks of associations suggest that simplistic approaches to combating such conspiracy theories—either by moderating content on social platforms or educating users to be skeptical of information—may not be effective.

This does not mean that there is no way out of the rabbit hole. There are many strategies that have not been tried. Designing algorithms that encourage consensus as opposed to exacerbating division could help, as would programs and policies that build bridges among users rather than dividing them along ideological or party lines. And although it won't result in instant change, continuing to invest in public education that explains scientific methods—what scientists know but also what they do not know—could rebuild trust in science as a whole and make scientific concepts less likely to be glommed in with other conspiracies. Ultimately, to stall conspiracies online, researchers will need to look to the real world and acknowledge and address why antagonism and antipathy toward science become attractive.

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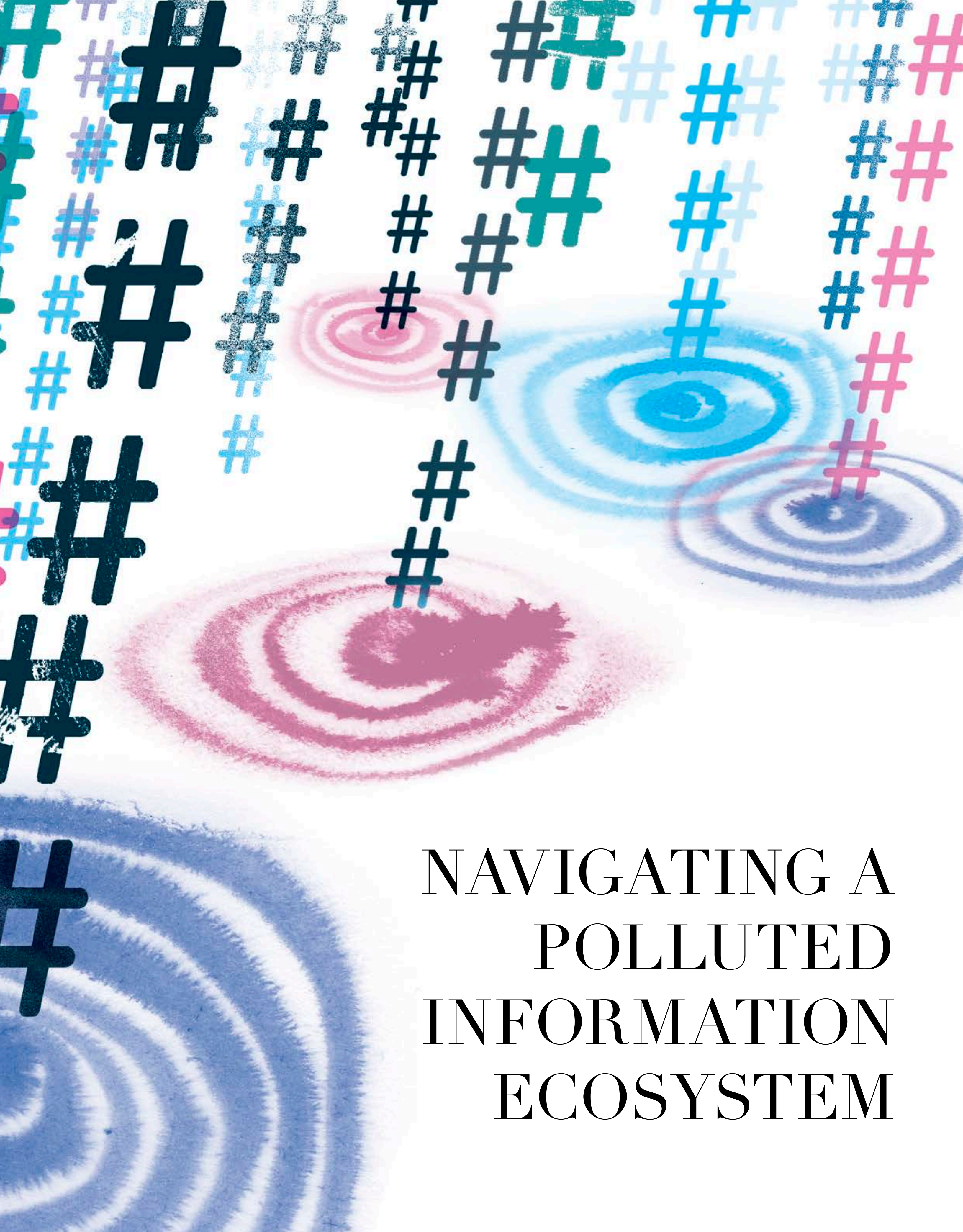
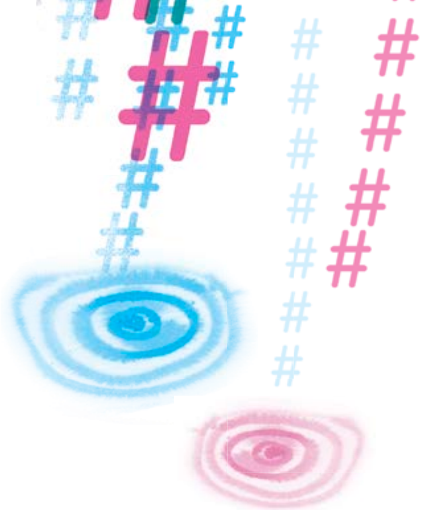


NAVIGATING A POLLUTED INFORMATION ECOSYSTEM



CLAIRE WARDLE

Misunderstanding Misinformation

An obsession with gauging accuracy of individual posts is misguided. To strengthen information ecosystems, focus on narratives and why people share what they do.

In the fall of 2017, Collins Dictionary named *fake news* word of the year. It was hard to argue with the decision. Journalists were using the phrase to raise awareness of false and misleading information online. Academics had started publishing copiously on the subject and even named conferences after it. And of course, US president Donald Trump regularly used the epithet from the podium to discredit nearly anything he disliked.

By spring of that year, I had already become exasperated by how this term was being used to attack the news media. Worse, it had never captured the problem: most content wasn't actually fake, but genuine content used out of context—and only rarely did it look like news. I made a rallying cry to stop using *fake news* and instead use *misinformation*, *disinformation*, and *malinformation* under the umbrella term *information disorder*. These terms, especially the first two, have caught on, but they represent an overly simple, tidy framework I no longer find useful.

Both *disinformation* and *misinformation* describe false or misleading claims, but disinformation is distributed with the intent to cause harm, whereas misinformation is the mistaken sharing of the same content. Analyses of both generally focus on whether a post is accurate and whether it is intended to mislead. The result? We researchers become so obsessed with labeling the dots that we can't see the larger pattern they show.

By focusing narrowly on problematic content, researchers are failing to understand the increasingly sizable number of people who create and share this content, and also overlooking the larger context of what information people actually need. Academics are not going to effectively strengthen the information ecosystem until we shift our perspective from classifying every post to understanding the social contexts of this information, how it fits into narratives and identities, and its short-term impacts and long-term harms.

What's getting left out

To understand what these terms leave out, consider "Lynda," a fictional person based on many I track online. Lynda fervently believes vaccines are dangerous. She scours databases for newly published scientific research, watches regulatory hearings for vaccine approvals, reads vaccine inserts to analyze ingredients and warnings. Then she shares what she learns with her community online.

Is she a misinformer? No. She's not mistakenly sharing information that she didn't bother to verify. She takes the time to seek out information.

Nor is she a disinformation agent as commonly defined. She isn't trying to cause harm or get rich. My sense is that Lynda is driven to post because she feels an overwhelming need to warn people about a health system she sincerely believes has harmed her or a loved one. She is strategically choosing information to connect with people and promote a worldview. Her criteria for choosing what to post depends less on whether it makes sense rationally and more about her social identities and affinities.

Dismissing Lynda for her selective interpretation and lack of research credentials risks failing to see what she's accomplishing overall: taking snippets or clips that support her belief systems from information published by authoritative institutions (maybe an admission by a scientist that more research is needed, or a disclaimer about known side effects) and sharing that without any wider context or explanation. This "accurate" information that she has uncovered via her own research is used to support inaccurate narratives—perhaps that governments are rolling out vaccines for population control, or doctors are dupes or pharmaceutical company shills.

To understand the contemporary information ecosystem, researchers need to move away from our fixation on accuracy and zoom out to understand the characteristics of some of these online spaces that are powered by people's need for connection, community, and affirmation. As communications scholar Alice Marwick has written, "Within social environments, people are not necessarily looking to inform others: they share stories (and pictures, and videos) to express themselves and broadcast their identity, affiliations, values, and norms." This motivation can apply to Beatles fans as well as to cat lovers, activists for social justice, or promoters of various conspiracy theories.

Siloed research

Lynda's online world points to something else that the labels misinformation and disinformation cannot capture: connections. While Lynda might post primarily in anti-vaccine Facebook groups, if I follow her activities, it's very likely I'll also find her posting in #stopthesteal or similar groups and sharing climate denial memes or conspiracy theories about the latest mass shooting on Instagram. But that's a big if; no one expects me as a researcher to ask questions so broadly.

One of the challenges of studying this arena is that its narrow focus means that the role of the world's Lyndas is barely understood. A growing body of research points to the volume of problematic content online that can be traced back to a surprisingly small number of so-called superspreaders, but so far even that work studies those who amplify content within a particular topic rather than create it—leaving the impacts of devoted true believers like Lynda still understudied.

This reflects a larger issue. Those of us who are funded to track harmful information online too often work in silos. I'm based in a school of public health, so people assume I should just study health misinformation. My colleagues in political science departments are funded to investigate speech that might erode democracy. I suspect that people like Lynda drive an outsize amount of wide-ranging problematic content, but they do not operate the way we academics are set up to think about our broken information systems.

Every month there are academic and policy conferences focused on health misinformation, political disinformation, climate communication, or Russian disinformation in Ukraine. Often each has very different experts talking about identical problems with little awareness of other disciplines' scholarship. Funding agencies and policymakers inadvertently create even more siloes by concentrating on nation states or distinct regions such as the European Union.

Events and incidents also become silos. Funders fixate on high-profile, scheduled events like an election, the rollout of a new vaccine, or the next United Nations climate change conference. But those trying to manipulate, monetize, recruit, or inspire people excel at exploiting moments of tension or outrage, whether it's the latest British royals documentary, a celebrity divorce trial, or the World Cup. No one funds investigations into the online activity *those* moments generate, although doing so could yield crucial insights.

> **People aren't influenced by one post so much as they're influenced by the narratives that these posts fit into.**

Authorities' responses are siloed as well. In November 2020, my team published a report on 20 million posts we had gathered from Instagram, Twitter, and Facebook that included conversations about COVID-19 vaccines. (Note that we didn't set out to collect posts containing misinformation; we simply wanted to know how people were talking about the vaccines.) From this large data set, the team identified several key narratives, including the *safety, efficacy, and necessity* of getting vaccinated and the *political and economic motives* for producing the vaccine. But the most frequent conversation about vaccines on all three platforms was a narrative we labeled *liberty and freedom*. People were less likely to discuss the safety of the vaccines than whether they would be forced to get vaccinated or carry vaccine verification. Yet agencies like the Centers for Disease Control and Prevention are only equipped to engage the single narrative about safety, efficacy, and necessity.

Not "atoms," but narratives and networks

Unfortunately, most scholars who study and respond to polluted information still think in terms of what I call *atoms of content*, rather than in terms of narratives. Social media platforms have teams making decisions about whether an individual post should be fact-checked, labeled, down-ranked, or removed. The platforms have become increasingly deft at playing whack-a-mole with posts that may not even violate their guidelines. But by focusing on individual posts, researchers are failing to see the larger picture: people aren't influenced by one post so much as they're influenced by the narratives that these posts fit into.

In this sense, individual posts are not atoms, but something like drops of water. One drop of water is unlikely to persuade or do harm, but over time, the repetition starts to fit into overarching narratives—often, narratives that are already aligned with people's thinking. What happens to public trust when people repeatedly see, over months and months, posts that are "just asking questions" about government institutions or public health organizations? Like drops of water on stone, one drop will do no harm, but over time, grooves are cut deep.

What is to be done?

Over the past few years, it's been much easier to blame Russian trolls on Facebook or teenage boys on 4chan than to recognize how those tasked with providing clear, actionable information to meet communities' needs have regularly failed to do so. Bad actors who are trying to manipulate, divide, and sow chaos have taken advantage of these vacuums. In this confusing space, trusted institutions have not kept up.

To really move forward, proponents of healthy information ecosystems need a broader, integrated view of how and why information circulates.

Organize and fund cross-cutting research. Those hoping to foster healthy information ecosystems must learn to assess multilingual, networked flows of content that span conventional boundaries of disciplines and regions. I chaired a taskforce that proposed a permanent, global institution to monitor and study information that would be centrally funded and thus independent of both nations and tech companies. Right now, efforts to monitor disinformation often do overlapping work but fail to share data and classification mechanisms and have limited ability to respond in a crisis.

Learn to participate. The polluted information ecosystem is participatory—a site of constant experimentation as participants drive engagement and better connect with their audiences' concerns. Although news outlets and government agencies appear to embrace social media, they rarely engage the two-way, interactive features that characterize web 2.0. Traditional science communication is still top down, based on the paternalistic deficit model, which assumes that experts know what information to supply and that audiences will passively consume information and respond as intended. These systems have much to learn from people like Lynda about how to connect with, rather than present to, audiences. An essential first step is to train government communications staff, community organizations, librarians, and journalists to seek out and listen to the public's questions and concerns.

Support community-led resilience. Today, global and national funders have an outsized focus on platforms, filters, and regulation—that is, how to expunge the "bad stuff" rather than how to expand the "good stuff." Instead of pursuing such whack-a-mole efforts, major funders should find a way to support specific place-based responses for what communities need. For example, health researcher Stephen Thomas created the Health Advocates In-Reach and Research (HAIR) campaign that trains local barber shop and beauty salon owners to listen to their customers about health concerns and then to provide advice and direct people to appropriate resources for follow-up care. And after assessing information needs of the local Spanish-speaking community in Oakland, California, and finding it woefully underserved, journalist Madeleine Bair founded the participatory online news site *El Tímpano* in 2018.

Targeted "cradle to grave" educational campaigns can also help people learn to navigate polluted information systems. Teaching people techniques such as the SIFT method (which outlines steps to assess sources and trace claims to their original context) and lateral reading (which teaches how to verify information while consuming it) have been proven effective, as have programs to equip people with skills to understand how their emotions are targeted and other techniques used by manipulators.

For each of these tasks, people and entities hoping to foster healthy information ecosystems must commit to the long game. Real improvement will be a decades-long process, and much of it will be spent playing catch-up in a technological landscape that evolves every few months, with disruptions such as ChatGPT emerging seemingly overnight. The only way to make inroads is to look beyond the neat diagrams and tidy typologies of misinformation to see what is really going on, and craft a response not for the information system itself but the humans operating within it.

Claire Wardle *is cofounder and codirector of the Information Futures Lab and professor of the practice at the Brown University School of Public Health.*

KARI KIVINEN

In Finland, We Make Each Schoolchild a Scientist

Teaching research skills and encouraging inquiry from the earliest ages can build social resilience to misleading information.

Much of the conversation around misinformation and mistrust focuses on messengers and message systems. Some emphasize that policymakers and scientists must communicate more effectively, others that social media platforms must moderate content and revise their algorithms. The topic that is neglected is how individuals decide what information is trustworthy.

For most of the twentieth century, information was mediated by librarians, disciplines, experts, journalists, and others who determined which sources and details were valid and which were not. By contrast, members of today's society have all been entrusted with the responsibility to carry out that incredibly important task without really being aware of it. Just type a keyword into a search engine, and you'll get thousands of answers in the blink of an eye, with little sense of who is behind them or what their intentions are.

The challenge of modern life, then, is to navigate through these choices while filtering out misleading information, which has risen exponentially. I, and many other Finns, have come to believe that schools and education can help meet this challenge. Since 2017, when rankings began, Finland has earned the top spot in media literacy among European countries. These scores (derived from scores on press freedom, civic engagement, public trust, reading competency, and scientific literacy) are taken as a measure of resilience to fake news. Included in this measure is the fact that Finland also scores well in science in international student achievement assessments.

Every child a fact-checker

Kindergarten may seem like a counterintuitive place to fight "fake news," but Finland arrived at this approach by necessity. In 2014, at the time of national and European elections, the country observed an increasing flood of Russian propaganda, medical disinformation, climate denialism, and other misleading online content. That year, the Finnish nonprofit Faktabaari launched to provide fact-checking information about the elections. But it was quickly apparent that the service was inefficient, as so many more people access misleading content than relevant fact-checking material. The better route was to teach people to be their own fact-checkers, with a program of digital literacy.

As a director of a school in Helsinki with more than 800 pupils aged 5 to 18 years, I was excited to collaborate. A new Finnish curriculum was launched in 2016 with an element called "multiliteracy," which involved making sure children could competently navigate online media and social platforms. We realized quite quickly that fact-checking concepts and methods could be adapted to the school environment to support the new curriculum. Since 2017, as a pro bono expert, I have been leading Faktabaari EDU, a project that extends fact-checking skills into the classroom. In math lessons at my school, kids learn about how statistics can be deceptive; in history, they study propaganda campaigns from the past. Even folklore, in which the wily fox tries to trick his victims, reinforces the idea that active critical thinking should be a regular part of ordinary life.

We soon discovered that children enjoyed playing Sherlock Holmes when fact-checking the claims teachers gave them to be verified. After some trial and error, the teachers building the curriculum boiled down complex fact-checking methods into three fundamental questions: Who's behind the information? What's the evidence? What do other sources say? These questions are folded throughout the curriculum, across subjects, and there is continuity from year to year. Young children may learn to tell the difference between a mistake and a hoax, while older students may undertake more advanced projects on elections and threats to democracy.

To be sure, in some ways Finland is an outlier. Our resilience is partly cultural, but it has been developed intentionally during recent decades, in part because education is seen as part of collective civil defense. Our population is highly educated with strong levels of trust in other people, public news sources, and civic institutions. Since the 1980s, educational standards have required Finnish teachers to have a master's degree, which means they are all familiar with the research process. These teachers bring a culture of research into their classrooms and are empowered to design activities around students' ideas rather than relying on rote lesson plans.

In addition, Finland's education system reflects deep cultural values. International visitors to my school have been surprised to see that, in early childhood education, pupils spend nearly half of the day outdoors, in the school yard or in the nearby forest, exploring and having fun. According to the Finnish national curriculum for early childhood education, children have the right to play, to learn through play, to enjoy what they learn, and to build a sense of themselves, their identity, and the world according to their own starting points. Students in our classrooms are expected to think and to enjoy thinking. In secondary education, students have lessons in separate science subjects—but with the same hands-on experimental spirit.

Creating Sherlock Holmeses by the million

It would take a lot of time to copy the Finnish approach fully, but a host of experiments in the European Union and beyond suggest that the basic idea can be replicated. The European Commission Expert Group, on which I serve, has explored how education and training initiatives can tackle disinformation through digital literacy in schools throughout Europe. We have produced a report and practical guidelines for teachers and other educators on tackling disinformation, which include activity plans and insights on how to create student-centered approaches. One of the central challenges is that teachers need training, guidance, and support as well as ways to measure the effectiveness of these lessons.

Although much work remains to be done in developing an evidence-based curriculum, the evidence is accumulating that these interventions are effective. A study conducted in 2019 with nearly 500 high school students in a US school district found that just a half-dozen 50-minute lessons could help students demonstrate appropriate skepticism of online information. One exercise asked students to look at a tweet of a child supposedly in Syria lying between two mounds described as his parents' graves. (In fact, the child was in Saudi Arabia posing for an art project between piles of rocks.) Students received credit for noting that the post did not identify the tweet's author and for questioning what the image really showed. Another exercise involved tracking a website's sponsor to an oil company.

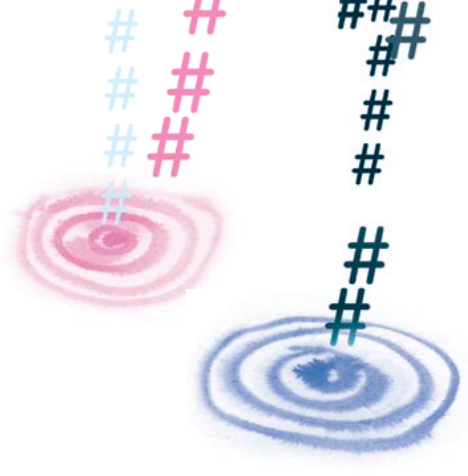
Wealthy countries are not the only ones that can use these interventions. A cluster-randomized controlled trial in Uganda found that a series of nine 80-minute lessons given to 10- to 12-year-olds could help them assess claims about health treatments. (Schools in the program received two days of teacher training in the curriculum, a textbook, teacher's guide, and other materials developed in consultation with Ugandan teachers.) A commentary in *The Lancet* praised the program for showing such education was possible "even in resource-poor settings with large student to teacher ratios."

But this kind of curriculum is far from mainstream. A recent Stanford University-led study that resulted in the report *Science Education in an Age of Misinformation* brought together more than a dozen international experts, including myself, to consider the problem. One of our conclusions was that classroom instruction too often focuses on transmitting simple facts. Science educators have a new, critical responsibility to ensure that their students are equipped with skills that can guard them against pseudoscientific online claims.

In practice, that means science teachers should explain how knowledge is established in science, that science is committed to producing knowledge based on testing evidence, and that is why scientific knowledge can be trusted. The Stanford study recommended revisions toward this end in educational standards, curricula, and teacher training. Moreover, assessments must be revamped to test whether students can find flaws in scientific arguments and evaluate the credibility of sources.

Of course, schools alone will not eradicate misleading information or people's susceptibility to it. But teacher guidelines, focused curricula, and educational standards are an essential part of the solution. Society must pay at least as much attention to children's minds as to social media algorithms.

Kari Kivinen *is the education outreach expert of the EUIPO Observatory, former secretary-general of the European Schools, and ex-head of the French-Finnish School of Helsinki.*



JACK STILGOE

Viral Suppression

When Facebook's fact-checkers slapped a "missing context" label on a venerable medical journal's article about breached vaccine trial protocols, they set off a very twenty-first-century fight about who should play what role in scientific communication.

In November 2021, an investigative story in the *British Medical Journal* (*BMJ*) with the headline "Covid-19: Researcher blows the whistle on data integrity issues in Pfizer's vaccine trial" received more than 3.5 million hits. Altmetric, a company that measures scientific papers' online attention, scored the article as the third most-shared research output of all time.

It also soon fell foul of mechanisms Facebook had put in place to stop misinformation. Those attempting to share the article received a message saying that independent fact-checkers had found it was "missing context." Those running Facebook groups whose members shared the article were told there was "partly false information in your group."

BMJ responded with fury. It posted an open letter to Mark Zuckerberg, cofounder of Facebook and CEO of its parent company, Meta, calling the fact check "inaccurate, incompetent, and irresponsible." The 182-year-old journal objected to being characterized as a news blog, being included on a URL address that contained the phrase "hoax-alert," and having a stamp marked "flaws reviewed" on a screenshot of the article. It emphasized that the article contained no outright errors and accused Facebook's fact-checker, a third-party company called Lead Stories, of unjustified censorship.

Lead Stories responded that *BMJ*'s article had a "scare headline" with analysis that "oversells the whistleblower and overstates the jeopardy," which resulted in "hundreds of Facebook posts and tweets, many by anti-vaccine activists using it as 'proof' the entire clinical trial was fraudulent and the vaccine unsafe." The response also noted that Facebook had not restricted traffic or visibility but "merely warned of missing context." That label, according to Facebook's guidelines, is applied to content that may mislead or "content that implies a false claim without directly stating it."

Accusations and name-calling pinged and ponged over Twitter. Lead Stories tweeted at the journalist who wrote the article, Paul Thacker, asking whether he minded being republished by the "Disinformation Dozen," a small group identified by the nonprofit Center for Countering Digital Hate as spreading about two-thirds of the COVID-19 misinformation on social media. Thacker addressed Lead Stories as "You moron" and accused its team of trolling.

As a professor of science and technology policy at University College London, part of my job is studying public debates about science. I was intrigued that an esteemed journal like *BMJ* had been called out this way. I posted on Twitter that it would be a fascinating case study. Lead Stories responded: "When a reputable medical journal is so good at science communication that its article is republished verbatim by anti-vaccine activists because it can be easily misinterpreted to mean something it doesn't, yes, that is quite the case study."

The deeper I dug into this case, the more complicated it became. But ultimately, it boils down to competing assumptions about healthy information ecosystems and the role organizations such as *BMJ* and Facebook (and the fact-checkers they deploy) should play within these ecosystems. By focusing on the *BMJ* story's heavy traffic and its use in narratives that went beyond the article's explicitly stated claims, Lead Stories was, first, trying to control how the story would be used by people they saw as bad actors and, second, trying to control the spread of the story. By contrast, *BMJ* sought to ask important questions about shoddy oversight of clinical trials. *BMJ* did not address the issue of readers' overinterpretation or promotion by anti-vax websites. Rather, it pointed to its own august reputation, the story's lack of outright factual errors, and an (anonymous) external peer review as exempting it from Facebook's labeling.

Although *BMJ*'s articles generally come from academics and clinicians, the November piece was a feature story written by an investigative reporter. But conventional research articles have also been caught in social media platforms' fact-checking apparatus. One example of this involves Cochrane, a well-respected British nongovernmental organization that conducts rigorous systematic reviews of clinical treatments by collecting published articles, evaluating their quality, and publishing an overarching assessment of the state of the evidence. Around the same time *BMJ* published its article, Cochrane complained that Instagram users mentioning Cochrane's work received warnings that the organization had "repeatedly posted content that goes against our Community Guidelines on false content about COVID-19 or vaccines." After several weeks, prohibitions were lifted, though without any explanation I could find. Like Facebook, Instagram is owned by Meta, but even for those inside the process, the lines between what is deemed factually acceptable and what is not appear to be blurry: in its response to *BMJ*'s open letter, which mentioned Instagram's treatment of Cochrane, Lead Stories said that it had no role in this decision and added that Cochrane's content should "probably not be blocked."

What these tangles with reputation, misinformation, social media, and polarization show is that the players and the power in science communication are shifting. For most of science's history there has been a presumption that communication should be one-way (from the experts to the public) and tightly controlled (by the experts). More recently, there has been a democratic shift toward open dialogue, something that social media platforms can sometimes facilitate. But in practice, social media can also boost misinformation, contributing to political polarization and threatening public health. The pandemic has raised the stakes of information quality and distribution while also increasing the number and types of people paying attention to scientific publishing. The roles that media, the public, government, and scientific publishers play in disseminating, validating, and debating content are all in flux.

Disorganized skepticism

Robert Merton, a leading light of twentieth-century sociology, argued in the 1940s that science derives its authority in part from its "organized skepticism." Science, he contended, progressed through constant scrutiny, but this scrutiny happened within its own citadel. Mechanisms of peer review and "invisible colleges" such as the United Kingdom's Royal Society were seen as guarantees. Asking questions was encouraged, but only for those with institutionalized authority. The number of times an article was cited by other scientists was considered a proxy for the importance of a piece of research (and the researchers who conducted it).

Online access has changed this radically, providing quick, open forums for critique. The amount of attention scientific articles attract is being measured and valued in new ways—ones that many journals and researchers actively seek to maximize. Despite the fact that social media prioritizes engagement over quality, tools like Altmetrics are increasingly used to measure and celebrate such attention. Although *BMJ*'s target audience is practicing medical doctors, the journal decided to provide its reporting on COVID-19 to the public for free, which doubled their website traffic during the pandemic. Of the 100 scientific articles with the highest Altmetric score in 2021, 98 were about COVID-19, including papers on ivermectin and hydroxychloroquine, two drugs that repeatedly failed to demonstrate efficacy yet received cult status among vaccine sceptics. Like *BMJ*, many journals have come to value high click rates and shares by nonspecialists, although I have seen little reflection on the changing role of these publications in a social media world.

The twenty-first century brought recognition that past notions of one-way science communication—also known as the "knowledge deficit model"—were both simplistic and paternalistic. Effective science communication requires dialogue with the public, not heavy-handed preaching. Clinicians now increasingly ask patients' opinions when recommending treatments, and policymakers acknowledge the need to listen to citizens' attitudes on new technologies such as synthetic biology or artificial intelligence.

Meanwhile, the internet has radically democratized access to information and the tools of research, completely transforming the news landscape. By 2016, more than half of internet users said they used social media for news at least weekly. What information is most visible in people's feeds is increasingly shaped by social media algorithms. People who would previously not have explored scientific journals share articles on social media. Some leverage the authority of accredited scientists and peer-reviewed journals to support their views.

The COVID-19 pandemic accelerated these trends. Conventional science journalists have been joined by a host of other communicators whose stories only reflect the uncertainties of science when it suits their narrative. All through the height of the pandemic, *The Joe Rogan Experience* was one of the world's most popular podcasts, with more than 10 million subscribers. It features a controversial host who provides a platform for issues such as the efficacy of unorthodox COVID-19 treatments with the catchphrase "I'm just asking questions."

The early panic of the pandemic saw a retreat to some paternalistic approaches to science communication in the United States, United Kingdom, and elsewhere. Scientists, public authorities, and others were alarmed by the narratives spreading through the internet, convinced that public trust in science, so crucial to vaccination campaigns and efforts to forestall infection and disease, was being sabotaged. Some scientific organizations fell back on what communication scholars Matthew Nisbet and Dietram Scheufele describe as the "still dominant assumption that science literacy is both the problem and solution to societal conflicts."

Anything that was seen as undermining or even scrutinising the COVID-19 vaccines' safety record attracted disproportionate concern. As early as April 2020, Facebook created a special COVID-19 policy to combat misinformation: it produced a list of claims that it would prohibit in posts and ads and announced that it would boost funding for both algorithmic fact-checkers and human ones. The company boasted that when users saw posts that had been flagged, "95% of the time they did not go on to view the original content."

Several months before its whistleblower article was flagged, *BMJ* had aired concerns of overreach. In May 2021, a feature story asked, "Who fact checks the fact checkers?" The piece explained that Facebook had "removed 16 million pieces of its content and added warnings to around 167 million." It pointed to the "the difficulty of defining scientific truth" and questioned whether social media platforms should be charged with the task.

Blunt and sharp tools

In November 2021, *BMJ* published Thacker's reported story, which focused on Ventavia Research Group, a company running three sites in Texas as part of Pfizer's 153-site COVID-19 vaccine clinical trial. A whistleblower at the company provided evidence that patients were inadequately monitored after receiving vaccines, their treatment status had potentially (and inappropriately) been disclosed to clinicians, biohazard waste had been improperly disposed of, and data had been recorded irresponsibly.

In my interview with Rebecca Coombes, *BMJ*'s head of journalism, she told me there was a clear public interest in reporting on the whistleblower. "We were presented with very hard evidence of serious problems that had occurred in one of the world's most important, valuable pharmaceutical products, the Pfizer vaccine." Coombes was well aware that COVID-19 vaccines were being watched closely by those looking to exaggerate concerns about their safety or efficacy. "It is very important that the *BMJ* doesn't lose its courage at times like this," she told me. "It's still important to ask the big questions." She criticized Lead Stories for noting that a Twitter account associated with the whitleblower had also promoted anti-vaccine content as "guilt by association."

Three days after *BMJ* published its account, a false story appeared on a now-defunct Canadian website, the *Conservative Beaver*, claiming that the Pfizer CEO had been arrested and that this news was being suppressed by US outlets. The story was quickly debunked, but the rumor continued to circulate within social media. The *Conservative Beaver* page included a tweet from *BMJ* about the Ventavia whistleblower, providing a grain of truth around which people could weave the conspiracy.

Alan Duke, the editor-in-chief at Lead Stories, told me he saw "a big problem that it was *BMJ*, and that made it become more viral, more effective in the hands of the anti-vaxxers." Lead Stories said their concern was that the piece was being "wildly misinterpreted by many people." Rather than focusing on the details of *BMJ*'s reporting, its statement focused on missing perspectives and the broader message: "Did the British Medical Association's news blog reveal flaws that disqualify the results of a contractor's field testing of Pfizer's COVID-19 vaccine, and were the problems ignored by the Food & Drug Administration and by Pfizer? No, that's not true … The benefits of the Pfizer vaccine far outweigh rare side effects and the clinical trial data are solid."

But a close reading of *BMJ*'s article shows that the article didn't explicitly say that results of the Pfizer's trial were invalidated or explore implications for the risks and benefits of Pfizer's vaccine. Nor did the original article include any wording to discourage this interpretation. And while it stated that blinding was not maintained properly and that patients were not monitored appropriately following vaccination, it did not explore whether and how results might have been compromised or whether patients were indeed harmed. The text also did not provide a response from Ventavia or Pfizer about the accusations presented in the article.

Other outlets responded with their own context-setting articles: one, titled "Experts Blow Whistle on Alleged COVID Vaccine Whistleblower Claims," from MedPage Today, quoted a physician who described the allegations against Ventavia as a "vague kind of handwaving." A story from a CBS affiliate in North Carolina carried the headline "Fact check: Report questioning Pfizer trial shouldn't undermine confidence in vaccines." (Although I didn't ask her about these specific articles, Coombes told me that her team at *BMJ* was "very careful not to overplay the findings.")

From Lead Stories' perspective, *BMJ*'s authority and its rigorous internal fact-checking added to the problem. The story was dangerous in the hands of anti-vaxxers not because it was false, but because it was true—and so easily overinterpreted. Lead Stories editor Dean Miller thought *BMJ* was being naïve in the face of coronavirus conspiracies, telling me, "If you're going to handle sharp tools, you should use them well."

BMJ did not engage with Lead Stories' concerns about misinterpretation. Announcing plans to appeal to Facebook's Oversight Board, *BMJ* editor-in-chief Kamran Abbasi raised his own concerns about the platform's motivations: "The real question is: why is Facebook acting in this way? What is driving its world view? Is it ideology? Is it commercial interests? Is it incompetence? Users should be worried that, despite presenting itself as a neutral social media platform, Facebook is trying to control how people think under the guise of 'fact checking.'"

When I asked editor Dean Miller whether Lead Stories thought the public could be trusted to deal with uncertainty, he responded, "Don't condescend to the public. They can figure it out. They can muddle through all this and decide what to believe."

The fact-checkers' actions, however, suggest a different ethos. In conversations, I felt the Lead Stories editors revealed an old-fashioned model of paternalism, deployed through new means. They took a Manichean view, presuming that views could be separated into pro- or anti-science and pro- or anti-vaccine and that people could be divided into those with good intentions and those with bad intentions.

There are many within science who believe that, like laws and sausages, the public should not look too carefully at the processes by which scientific knowledge is made. Instead, we should just appreciate the end product. *BMJ* invited its readers backstage, into a debate about the processes of science—but stopped short of examining or intervening in what narrative played out in the social sphere.

The COVID-19 pandemic, with its high stakes, large uncertainties, and urgent need for decisions, is a case of what philosophers of science Silvio Functowicz and Jerry Ravetz call "postnormal science," in which the old assumptions about scientific reliability look shaky. According to Functowicz and Ravetz, the answer in such cases is not to defend the barricades of laboratory science, but instead to seek "extended peer review" in the form of more dialogue with the public, building what sociologist Helga Nowotny and colleagues call "socially-robust knowledge." For public health issues, particularly those involving vaccination, this would mean a greater emphasis on local conversations. Dialogue between community doctors and citizens, for instance, could complement and inform top-down campaigns.

For most of its history, science communication has depended on good-faith actors: benevolent scientists inform a receptive public of their discoveries. The presumption of good faith was based on Robert Merton's old idea of organized skepticism—that science was a self-governing entity. The question with today's decidedly disorganized skepticism is how new models of trust can be built.

In this environment, fact-checking might help interrupt the spread of obvious falsehoods, but it won't resolve emerging situations in which evidence cannot be separated from its context. Tedros Adhanom Ghebreyesus, director-general of the World Health Organization (WHO), told a security conference in February 2020, "Fake news spreads faster and more easily than this virus, and is just as dangerous." But his call for "facts, not fear" was undermined by the uncertainties that inevitably accompany a new disease. As evidence accumulated, WHO itself had to change its messaging about whether COVID-19 was airborne and whether wearing masks curbed its spread.

Fact-checking is a naïve response to a complex problem. Facebook's fact-checkers face an impossible task, unable to control the tide of information promulgated by Facebook's algorithms, which are tuned to emphasize controversy over veracity. As scholars such as sociologist Tarleton Gillespie have explained, Facebook, though claiming to be merely a platform, plays a powerful but chaotic editorial role.

Overall, social media invites conversation that is contentious rather than constructive. In my opinion, Lead Stories' belligerence triggered an overly defensive reaction from *BMJ*. It stepped on *BMJ*'s editorial responsibilities, adding a label without first offering suggestions or improvements. And while *BMJ*'s Coombes complained to me that the institution suffered "reputational damage" because of labels that discouraged online sharing, the publication does not seem to have yet worked out what its new roles and responsibilities should be in a world of online sharing. Tellingly, *BMJ* never issued a statement to clarify that its article was about clinical trial oversight, not about the vaccine's effectiveness.

Social media companies' importance to science communication will continue to grow, but they have resisted engaging with their responsibilities as publishers. And as science publishers are pressured to become more transparent, so should platforms. To start, they should allow probes of their own algorithms. Meta's Oversight Board, a body of journalists, scholars, lawyers, and others, is a case in point. A recent story in *WIRED* reported that the board's remit is to cover posts and content, not the algorithms that influence users' attention, and that relations between Meta and the board have been fractious. If there is no way to scrutinize the wellspring for how so many people now receive information about science, it will be harder to fix problems downstream. In an ecosystem where algorithms encourage engagement, controversy, and trolling, information presented to suit charged narratives will spread.

Simple fact-checking cannot solve this problem. Social media companies should seek healthy relationships with conventional science publishers, and science publishers should return the favor. Solutions will require dialogue with platforms such as Facebook, transparency about social media algorithms, new institutions capable of protecting the public interest, and resources to pursue solutions. It is indeed time to bring the public behind the scenes of science, but this brings with it new questions and editorial responsibilities.

There are many within science who believe that, like laws and sausages, the public should not look too carefully at the processes by which scientific knowledge is made.

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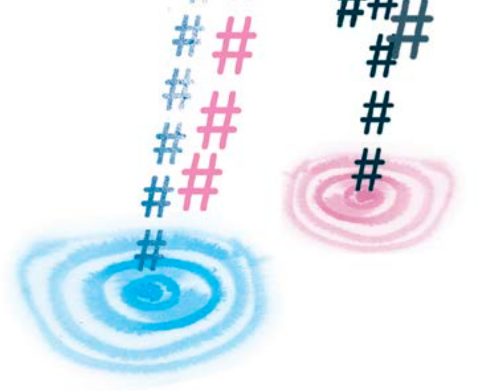

EMMA S. SPIRO AND KATE STARBIRD

Rumors Have Rules

Decades-old research about how and why people share rumors is even more relevant in a world with social media.

Around the time the US government was testing nuclear bombs on Bikini Atoll in the spring of 1954, residents of Bellingham, Washington, inspected their windshields and noticed holes, pits, and other damage. Some blamed vandals, perhaps teenagers with BB guns. Once Bellingham residents reported the pits, people in nearby towns inspected their windshields and found similar damage. Could sand fleas have caused it? Or cosmic rays? As more people examined their windshields and found more pits, a frightening hypothesis emerged: nuclear fallout from government hydrogen bomb testing. Within a week, people around Seattle, 90 miles away, were reporting damage as well.

But the rumors faded almost faster than they began as scientists and local authorities refuted the most prominent theories. What would become known as the "Seattle windshield pitting epidemic" became a textbook example of how rumors propagate: a sort of contagion, spread through social networks, shifting how people perceive patterns and interpret anomalies. Car owners saw dings that they'd previously overlooked and shared observations with others, who repeated the process.

Today this phenomenon would probably be described using the terms *misinformation*, *disinformation*, and perhaps *fake news*. Certainly, communication has changed dramatically since party-line telephone calls and black-and-white television, but scholarship from that era holds critical insights that are essential to the digital era. The study of rumors, which surged around World War II, is still very relevant.

Our team of researchers at the University of Washington have been investigating these issues for more than a decade. Initially, we centered our research on rumors. But we shifted focus in 2016 as public and academic attention lasered onto misinformation and social media manipulation. By 2020, our collaborators in an effort called the Election Integrity Partnership had developed an analytical framework that allowed dozens of students to scour social media platforms in parallel, feeding information to trained researchers for analysis and to authorities and communicators for potential mitigation. As we worked to build ways to quickly prioritize unsubstantiated claims about election processes and results, we found that the terms *misinformation* and *disinformation* were often cumbersome, confusing, or even inaccurate. But we came full circle in 2022, during a second iteration of our collaboration on election integrity, because the concept of rumors worked easily and consistently to assess the potential for unsubstantiated claims to go viral online.

We are convinced that using rumor as a conceptual framework can enhance understanding of today's information systems, improve official responses, and help rebuild public trust. In 2022, we created a prioritization tool around the concept of rumors. The idea was to help anticipate rumors that could undermine confidence in the voting process and assess whether a given rumor would go viral. Much of the concept's utility is that responders can engage with an information cascade before veracity or intent can be determined. It also encourages empathy by acknowledging the agency of people spreading and responding to rumors, inviting serious consideration of how they can contribute to the conversation.

A brief history of rumors

In the scholarly literature, *misinformation* refers to content that is false but not necessarily intentionally so; *disinformation*, which has roots in Soviet propaganda strategies, refers to false or misleading content intentionally seeded or spread to deceive. These terms are useful for certain problematic content and behavior, but they are increasingly politicized and contested. Mislabeling content that turns out to be valid—or potentially valid, like the theory that COVID-19 began with a so-called lab leak—violates public trust, undermines authorities' credibility, and thwarts progress on consequential issues like strengthening democracy or public health. In contrast, the label of *rumor* does not declare falsity or truth.

Rumoring can be especially valuable when official sources are incentivized to hide information—for example, when an energy company is withholding information about pollution, or when a government agency is covering up incompetence. Branding expert Jean-Noël Kapferer posits that rumors are best understood not as leading away from truth, but as seeking it out.

Historically, researchers defined rumors as unverified stories or "propositions for belief" that spread from person to person through informal channels. Rumors often emerge during crises and stressful events as people come together to make sense of ambiguous, evolving information, especially when "official" information is delayed. In this light, the numerous rumors that spread in the early days of the pandemic about its origins, impacts, and potential antidotes are unsurprising.

Both the production and spread of rumors are often taken as a natural manifestation of collective behavior with productive informational, social, and psychological roles. For instance, rumors help humans cope with anxiety and uncertainty. A population coming to terms with the risks of nuclear weapons could find a way to voice fears by seeing dings in the windshields of their Ford Thunderbirds and Chevrolet Bel Airs. Recognizing these informational and emotional drivers of rumoring can support more empathetic—and perhaps more effective—interventions.

Recentering rumor

When our research team tracked the use of social media in the 2010 Deepwater Horizon oil spill and the 2013 Boston Marathon bombings, we grounded our work in scholarship of offline rumors. Both events catalyzed numerous rumors: conspiracy theories warning about an impending sea floor collapse, crowd-sleuthed identifications of (innocent) suspects. We uncovered similar patterns in dozens of subsequent events where rumors circulated on social media, including a WestJet plane hijacking (that did not happen), multiple mass shootings in the United States, the downing of Malaysian Airlines flight 17 over Ukraine, and terrorist attacks in Sydney, Australia, in 2014 and Paris, France, in 2015.

Our rumor threat framework draws on much of the foundational social science research in rumoring to create the analytic categories, labeled "Dimensions" in Figure 1. These include underlying conditions (such as uncertainty or trust in official information), features of the rumor (such as novelty and emotional valence), and system effects (such as position in a social network). Both *uncertainty* and *significance* are rooted in the "basic law of rumor" introduced by scholars Gordon W. Allport and Leo Postman in 1946: the strength of a rumor is proportional to its significance to the listener multiplied by the ambiguity of the evidence around it. The condition of *diminished trust* stems from an idea of sociologist Tomatsu Shibutani from 1966, that informal communication surges in the absence of timely official information. The *familiarity/repetition* dimension arises from the "illusory truth effect," identified in the 1970s, that repetition increases believability. The seemingly contradictory feature of *novelty* tracks to work in 1990 showing that rumors lose value over time.

Assessing these dimensions helps predict which rumors will become viral. Take the 1950s Seattle windshield pitting epidemic: the underlying conditions included *high uncertainty* about both the cause of the windshield damage and the risks of nuclear fallout. The features of the rumor included *high significance* if the nuclear connection were true; *substantial novelty*, as both car ownership and concerns about nuclear weapons had become widespread in the years since World War II; *high emotional valence* pegged to nuclear fears as well as property damage; and *compelling evidence*, since people could see dings on their own cars and photographs of others. The system effects included *participatory potential* as people inspected and discussed their own cars. And, if contemporaneous accounts are true, the rumor declined because of high trust in the authorities who were debunking it.

Consider the COVID-19 pandemic. Every dimension of our framework shows rumor-promoting conditions. A novel virus with uncertain causes, serious consequences, unknown spreading mechanisms, and few remedies scores high in every category. Trust in government and local health officials started out low and declined from there. Impacts include lost lives, jobs, disrupted routines, and isolation—all of which heighten emotions. As for participation, many people all over the world were stuck in their homes and converged on familiar social platforms to share home remedies, hunts for toilet paper, stories of sick loved ones, reactions to lockdowns, and more, often with first-person accounts and video testimonials. Of course, some actors—both organized and disorganized—strategically manipulated information systems to gain attention, sell products, and push political agendas.

Ready for use

We initially developed this framework for research to guide our "rapid response" research. After conversations with local and state election officials who were struggling for guidance about when and how to address false claims about their processes and procedures, we adapted the framework for their perspective. Since then, we have presented it to a small number of local and state election officials for feedback. We aim to develop, deploy, and evaluate trainings based on the framework for 2024.

Though we developed techniques to classify rumors specifically for elections, we see potential for much wider application. Communicators can use the framework to assess vulnerability to rumors and to prepare for outbreaks or other foreseeable crises. Evaluating rumors across multiple dimensions for potential virality can be more useful than deciding whether to apply a label like misinformation or disinformation. It may not be worth drawing attention to a rumor likely to lapse, but it would be valuable to correct a harmful false rumor with high spread potential before it gets started. Such insights can inform how to focus crisis communication, platform moderation, or fact-checking resources.

Our framework may point to other actors and incidents

Figure 1: **THE RUMOR THREAT FRAMEWORK HELPS ASSESS WHETHER AN EVENT WILL GENERATE VIRAL RUMORS AND WHICH RUMORS WILL SPREAD**

GROUP	DIMENSIONS	DESCRIPTION
INFORMATION AND EVENT CONDITIONS	Uncertainty	As events (infections, train wrecks, elections) unfold, uncertainty powers both generation and spread of rumors. For specific rumors, ambiguous evidence will lead to more spread.
	Diminished Trust	Diminished trust in "official" information providers (government, media, etc.) pushes people toward more informal communication channels, catalyzing rumoring.
CONTEXTUAL FEATURES	Significance / Impact	The strength of a specific rumor is proportional to its importance in the lives of those spreading it. Events with greater potential impact on people's lives will catalyze more, and more viral, rumors.
	Familiarity / Repetition	A common set of building blocks underlie many rumors, which may make them resonate with familiarity. This, plus repetition, can enhance plausibility and boost spread.
	Novelty	People spread rumors to inform and entertain. Crises and other emergent events provide novel content that can be assembled into rumors.
	Emotional Valence	Rumors that stimulate strong emotions—including anger, fear, and outrage—will be more likely to spread. Events that stimulate strong emotions may catalyze the creation of viral rumors.
	Compelling-ness of Evidence	Evidence that piques interest and adds tangibility—e.g., first-person accounts, photos, and videos—will catalyze the creation and enhance virality of rumors.
	Participatory Potential	Rumors that allow people to participate—to add evidence or share their experiences and interpretations—are likely to spread further.
SYSTEMS EFFECTS	Position within the Social Network	Social networks shape the spread of rumors. Rumors will spread further if they reach central or high-audience nodes in a network or move from one network to another (e.g., a rumor in an anti-vaccine network jumps into ethnonationalist networks).
	Algorithmic or Network Manipulation	In online environments, rumors can be intentionally seeded or spread for strategic gain. Often those efforts game underlying networks and recommendation systems.

that require further consideration. For instance, online communities that actively engage in conspiracy theorizing are poised to project a common set of ideas onto events' causes and impacts. And sometimes the sorts of rumors an event will spawn are predictable. For those responding to the toxic train wreck in East Palestine, Ohio, for example, public discourse around oil spills and chemical accidents could reveal what likely rumors and conspiracy theories might appear.

Certainly, this framework cannot capture everything worthy of consideration. Practitioners should examine potential virality in tandem with the potential for harm. There are probably also productive approaches for refocusing the lens around misinformation and disinformation. For example, the term *misinformation* likely remains a better fit for describing false claims spread through low-quality scientific journals, and *propaganda* might better capture concerted efforts to manipulate the masses. *Disinformation* is useful for intentionally misleading and clearly manipulative campaigns.

However, we suspect the power of the rumor concept applies more broadly than misinformation and disinformation. Rather than going straight to the question of what to refute, authorities and analysts would first consider the role that a rumor is playing within the community—an approach that invites deeper insight.

Making the right calls on information is crucial because these phenomena are now inherently adversarial. Mistakenly assessing intent or accuracy can cause a responder to lose credibility. One overarching benefit of a framework like ours is that journalists, authorities, and researchers can get a handle on ever-shifting flows of ambiguous information without risking a reputation-damaging mistake.

More than that, by inviting a stance that seeks to engage with rumors rather than correct misinformation, the framework could make responses more resistant to bad-faith criticism. It could also allow communicators to acknowledge their own uncertainty, recognize the potential information in communities' rumors, and help rebuild lost trust. We hope this framework around rumors, and what others might build from it, can support quick, effective responses.

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How to Keep Emerging Research Institutions From Slipping Through the Cracks

The CHIPS and Science Act advances equity by codifying an underserved group, but more must be done to correct the effects of skewed research funding.

The CHIPS and Science Act, which became law in August 2022, is a major legislative accomplishment, reflecting bipartisan support to strengthen the US science and engineering enterprise. The legislation aims to bolster domestic research capabilities in myriad ways, from combating sexual harassment, which hinders organizational performance and employee retention, to establishing regional innovation hubs, which will stimulate investment in underserved jurisdictions. One little-recognized provision in the bill, also designed to bring more equity and effectiveness to science, is a new designation within higher education called emerging research institutions, or ERIs.

The CHIPS and Science Act defines an ERI as "an institution of higher education with an established undergraduate or graduate program that has less than $50,000,000 in federal research expenditures." While the concept of ERIs is not new, its codification will bring new benefits—for ERIs, their students, and science overall. Practically overnight, ERIs have entered both the lexicon and authorizing legislation of federal research agencies, including the National Science Foundation (NSF), Department of Energy (DOE), and Department of Defense. A DOE list developed in November 2022 includes more than 2,700 institutions.

The CHIPS and Science Act will improve equity and support workforce development by helping ERIs gain capacity to perform more research and become better integrated into federal science, technology, engineering, and mathematics (STEM) research and education programs. Already, research agencies have begun to boost capacity at ERIs, such as through the new solicitations from NSF's initiative GRANTED—Growing Research Access for Nationally Transformative Equity and Diversity—and DOE's Funding for Accelerated, Inclusive Research.

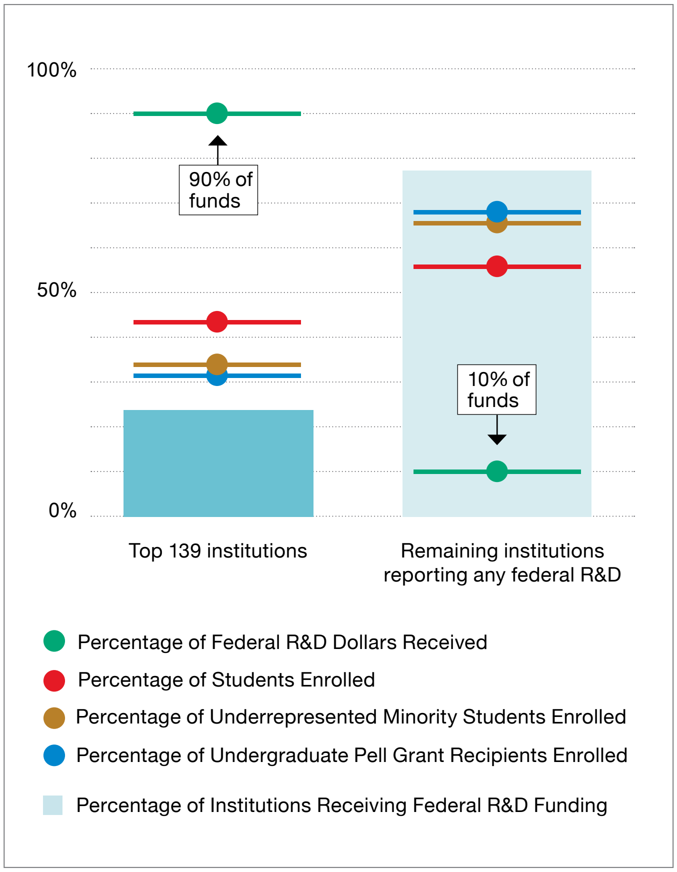
We worked for years to craft the ERI definition that came to fruition in the act. As administrators at Northern Illinois University (NIU), we held extensive conversations with federal agency officials and members of Congress and their staff, as well as experts across the higher education and scientific community. (Our colleague Dr. Sally Blake, chair of NIU's Department of Curriculum and Instruction, was exceptionally helpful in grounding arguments in academic literature.) Key to our presentation was data showing that federal research dollars could be better deployed to foster diverse STEM talent.

Our motivation is to redress the inequitable distribution of federal research funding, which has stark consequences: perpetuating regional imbalances and stymieing efforts to broaden participation in the STEM workforce. This imbalance in the funding of ERIs particularly harms students of color, low-income students, and rural students.

Other programs and designations exist to correct for imbalances, but our experiences at NIU showed us that critical gaps remain. NIU is a public, doctoral-awarding university serving 15,600 students. Nearly 80% of undergraduates are first-generation college students, federal Pell Grant recipients (i.e., low-income students), or students of color, and over 90% of undergraduate students are from the state of Illinois. But NIU is not designated as a minority-serving institution, nor is it in a so-called EPSCoR state, eligible for dedicated funding programs because the state receives such a small fraction of NSF funding. (EPSCoR, an NSF program, stands for Established Program to Stimulate Competitive Research). Designating institutions like NIU as ERIs will help ensure that they, and their students, no longer slip through the cracks.

But more should be done. Here we lay out why the ERI designation is useful and what policymakers, science agencies, well-established research institutions, and ERIs can do so that this designation strengthens science and equity.

Figure 1: **SCHOOLS THAT RECEIVE THE BULK OF R&D FUNDS DO NOT SERVE THE BULK OF STUDENTS**



Inequitable distribution of federal research funding hurts US science

In keeping with a long-standing pattern, most federal research dollars go to relatively few institutions. Even considering only the few hundred that award doctoral degrees (466 according to the latest Carnegie Classification of Institutions of Higher Education), a small subset of schools receives the bulk of federal funds, with R&D expenditures at the top 10—or 2%—of these institutions making up about 20% of the total. Indeed, the Association of American Universities, which represents less than 7% of research-active institutions, boasted of their "outsized role" spending more than 58% of all university R&D funds during federal fiscal year 2021.

An analysis published by the American Physical Society (in which we participated) found that 90% of federal R&D dollars in 2018 went to only 22% of 637 research-active institutions. In fact, the actual percentage is lower because institutions receiving negligible research funds are not counted in the federal data we used. These 139 institutions receiving 90% of the funds enrolled 43% of all students, 34% of students from underrepresented minority groups, and 32% of Pell Grant recipients. (And those figures are overestimated since so many ERIs are not included.) A preliminary analysis of 2021 data confirms these findings.

We understand the value of funding centers of excellence, but the current structure perpetuates a lack of diversity and fails to build capacity across the spectrum of institutions. Again, these numbers do not include the nearly 2,000 ERIs (as identified by DOE) that do not report into federal surveys because they receive practically no research funding.

This disconnect is damaging because it restricts students' opportunities to gain research experience. Participation in research is established as a high-impact practice to boost student retention and graduation and to diversify the STEM workforce. Undergraduate research experiences have been shown to increase student engagement and interest, foster a sense of belonging and self-efficacy, and raise graduation rates. Participation in research also prepares students to think critically, communicate their ideas, and apply their knowledge to their field—skills that are highly relevant in the workforce. Yet students at institutions with fewer researchers often encounter limited or no opportunities to engage in research and are less likely to be exposed to cutting-edge work.

ERIs fill a gap unmet by other designations

Concerns about the skewed distribution of research funding were expressed as early as the inception of NSF nearly seven decades ago. A patchwork of programs does exist to try to increase participation in STEM, diversify the STEM workforce, and disseminate federal resources more broadly; and it succeeds in creating official designations to recognize underserved populations and mobilize resources to their institutions. But, like any patchwork, it leaves out important segments of the targeted population.

For example, consider minority-serving institutions (MSIs). According to the National Science Board and the National Academies of Sciences, Engineering, and Medicine, MSIs can be defined historically, by legislation, by the percentage of minority student enrollment, or by other student body characteristics. Over several decades, new categories of MSIs were created to direct resources to institutions serving specific categories of minority students. According to a 2022 list, there are now seven different MSI distinctions and more than 860 MSIs.

Misconceptions abound regarding which institutions qualify as MSIs and which students are served by them. For example, historically Black colleges and universities (HBCUs, one MSI designation) are rightly lauded for their outsized role in educating Black scientists and engineers, especially doctorate recipients. Still, more than 85% of Black students who obtain bachelor's degrees do not attend HBCUs. This is not well known, and in fact we have been told by congressional staffers that they thought the exact opposite was true: that HBCUs enrolled up to 80% of Black college students. Although HBCUs are extremely important, equating HBCU enrollment with Black enrollment excludes the vast majority of Black students.

Other policymakers we've spoken with were shocked to learn that an institution could enroll over 50% students of color yet not qualify for federal MSI programs. According to our analysis of fall 2020 student enrollment data from the Department of Education, there are hundreds of institutions that fall into this category. NIU is one of them.

Another program that broadens the geographic distribution of federal research funding is EPSCoR, which is also a well-intentioned program where some institutions fall through the cracks. Institutions are eligible for EPSCoR support if they are in a state or territory that received 0.75% or less of NSF's budget for the last five years. Currently 25 states and three territories are eligible. But institutions that happen to be in the same state as highly funded research institutions lose out. For example, in Illinois, which is not an EPSCoR state, NSF data show that of the 16 Illinois institutions that received federal R&D funding, the top four institutions collectively received $1.6 billion while the remaining 12 institutions collectively received $178 million. In other words, 25% of Illinois research-active institutions received 90% of federal research funding directed to Illinois. In Michigan, the top three schools receive 93.7% of federal research funding for higher ed, and the remaining 17 research-active schools received 6.3%.

Nationwide, many institutions are, like NIU, neither MSIs nor in EPSCoR states and yet serve the same populations these programs target. Establishing ERIs as a category will help ensure that these institutions and their students are supported fairly.

Partnerships will strengthen ERIs and expand science

Lack of inclusion has hurt science by narrowing its workforce as well as its perspective. Promoting partnerships between ERIs and research-intensive institutions will broaden opportunity and diversity while doing more to serve the nation's research needs. Crucially, these partnerships must be structured to maintain the excellence of research-intensive institutions while also leveraging ERIs' ability to increase equity and build research capacities nationwide. Both aims can be achieved by requiring that high-research institutions create partnerships with ERIs when they host new initiatives, launch research centers, or receive large grants.

The CHIPS and Science Act includes language to foster partnerships between ERIs and high-research institutions through NSF and the DOE Office of Science. For example, ERIs are designated as fulfilling a partnership requirement for the NSF Regional Innovation Engines program, also created by the CHIPS and Science Act. The only mandatory ERI partnerships, however, require NSF to establish a five-year pilot program to apply to all multi-institution collaboration proposals with budgets exceeding $1 million. In an attempt to mitigate longstanding imbalances, the pilot program requires that at least 35% of an award go to the ERI partner(s) and that partnerships be "substantive, meaningful, sustainable, and mutually beneficial." The DOE Office of Science is directed to develop programs to increase the research capacity of ERIs; among the suggested mechanisms is "enabling mutually beneficial and jointly managed partnerships between research intensive institutions and ERIs."

> We understand the value of funding centers of excellence, but the current structure perpetuates a lack of diversity and fails to build capacity across the spectrum of institutions.

The devil is in the details: meaningful partnerships must ensure that expertise is shared and sustained. For example, a quantum science center established at a large, research-intensive university could provide fellowships for faculty members from their ERI partners—who would then return to their home universities and engage students in their research.

Another example involves creating paid research opportunities for undergraduates from partnering ERIs. Paid research positions, which can last a full academic year or span the summer break, have been shown to increase student retention rates in STEM, help students develop a sense of scientific identity and provide students with needed financial support. However, many NIU students cannot leave home for 10 weeks or more to do undergraduate research at a far-off campus due to jobs, caregiving responsibilities, and other ties. These place-bound students are especially impacted by highly concentrated federal research funding elsewhere.

Boost support for ERIs beyond CHIPS and Science

To get the most from ERIs and partnerships involving ERIs, several lines of follow-on action beyond the CHIPS and Science Act are needed. While the legislation includes authorizing language to benefit ERIs, strong annual appropriations are also necessary. The act includes more than 15 references to ERIs as priority recipients of federal funds, but this will do little to build research capacity at ERIs unless those funds are actually made available. Similarly, federal agencies and policymakers must fully consider implications when federal funding is directed to particular groups of higher education institutions. Most ERIs don't have dedicated employees working in government relations, so only a handful of professionals are focused on educating policymakers or looking out for ERIs as policy is crafted. The ERI Coalition, which one of us (Anna Quider) will co-run, will help meet these needs.

Beyond appropriation and authorization is the need to ensure that ERIs are represented across the wide array of authoritative advisory and evaluation bodies that chart the course for the US scientific enterprise. One simple step is auditing committee memberships. Publicly available membership lists (as well as our own experience) make it clear that affiliates from R1 universities, the most research-intensive institutions, dominate federal advisory bodies such as those convened at federal agencies (for example, NSF and the National Institutes of Health) and at federally-sponsored organizations (for example, the independent scientific advisory group JASON and the National Academies of Sciences, Engineering, and Medicine). Getting exact numbers is difficult, but we did access a publicly available database (maintained by the US General Services Administration) that tracks committees governed by the Federal Advisory Committee Act. Our analysis of NSF data from 2018 showed that, of the over 15,000 committee members affiliated with US institutions, 73% were from R1s. Minimizing inequities across federal research demands inclusion of ERIs from the beginning, when problems are defined, and all the way downstream, when recommendations are made and implementation assessed.

Assessment also needs more granular attention. Agencies should design grant processes to mitigate biases, such as blinding reviewers to both name and institution. NASA has seen great success with dual-anonymous peer review, which increased awards to female and early-career scientists. Another encouraging step in this direction is the National Institute of Health's recent move to change how grant applications are scored, "thus mitigating the undue influence of the reputation of the institution or investigator," according to a Center for Scientific Review description of the change. In a similar direction, the National Science Board voted at its February 2023 meeting to create a commission to assess NSF's grant review criteria and implementation.

Next year brings a broad, potentially transformative opportunity to revise metrics that have made the concentration of prestige and resources self-perpetuating. The R1 designation itself comes from the Carnegie Classification system deployed in 1970, which has tremendous reputational significance for universities offering doctoral degrees. R1, the most prestigious, is "very high research activity," followed by "high research activity" or R2, with all other doctoral universities designated "doctoral/professional universities" or R3. These classifications are based predominantly on the numbers of doctoral degrees awarded and the value of research expenditures. The American Council on Education is planning to update these research classifications for 2024. A de-emphasis on metrics that consider only the size of an institution's portfolio and an embrace of metrics to build and diversify the nation's research as a whole would have tremendous impact.

To truly achieve research equity, efforts to support ERIs must become incorporated into the fabric of the research ecosystem. As the CHIPS and Science Act moves into appropriation and implementation phases and beyond, all the key players will need to be on board. The concrete efforts we've seen so far are encouraging. We urge policymakers, along with agencies and universities, to lean into these new provisions for ERIs to form a more diverse, more equitable, and altogether stronger research enterprise.

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MICHAEL O. DIOHA AND ROSE M. MUTISO

Generating Meaningful Energy Systems Models for Africa

Bringing expertise, data, and model development "home" to African countries is interrelated and mutually reinforcing with achieving electrification, development, and climate goals on the continent.

About 77% of the 770 million people living without access to electricity today reside in sub-Saharan Africa (SSA). Increasing access to energy in the region could raise prospects for the 431 million residents there who live in poverty, while also advancing global climate goals. But the process of electrification has been hobbled by lack of data and one-size-fits-all energy system models that do not adequately reflect SSA's reality. Global institutions, as well as African governments, must begin to invest in the creation of national and regional energy models, data collection, and local expertise.

Most of the energy models applied to Africa are built and run by analysts in industrialized countries. As a result, the input of African analysts and local data can be limited, which results in poorly informed assumptions. For example, in 2015, the International Energy Agency (IEA) energy balance showed that Nigeria's household electricity consumption was 14 TWh. However, using Nigeria-specific data, a bottom-up energy modeling study conducted by Nigerian analysts in collaboration with the International Renewable Energy Agency (IRENA) showed that Nigeria's household electricity consumption in 2015 was 43 TWh. The estimate tripled because the IEA didn't adequately capture how many households had diesel and gasoline generators to back up the unreliable grid. Energy models contain many implicit assumptions, some of which—like gross domestic product (GDP), as we discuss below—are biased toward the expectations and priorities of industrialized countries, making them inappropriate for the SSA context.

Appropriate energy system models are essential for planning because they can be used to explore future energy demand and supply trajectories, incorporating projections of population, economic growth, and energy prices. Crucially, models can provide insights into how different policy and technological pathways could influence outcomes, including environmental sustainability and economic development. And they are often used by policymakers to make decisions about infrastructure development, investment, and trade-offs.

To perform their function well, models should be designed for local conditions, but the 48 diverse SSA countries are often lumped together. And even then, nearly three-quarters of studies published about modeling Africa's energy transition in the last two decades have used frameworks repurposed from other parts of the world. These one-size-fits-all models are further vexed by a lack of local data. In my (Michael Dioha's) own work on Nigeria, I'm often compelled to adapt foreign data. For my research on sustainable energy transitions, for example, I had to use foreign air pollutant emission factors because there were no data from Nigeria.

Inadequate modeling and insufficient data for SSA countries raise the risk that countries will make poor investments that lock them into expensive and polluting energy pathways, jeopardizing global climate goals as well as local development. A 2017 study noted that limited local data meant that many countries in the region were more likely to invest in coal and other fossil fuels because they couldn't recognize attractive renewable opportunities such as solar or wind. And a recent report from the Energy for Growth Hub (where we work) found that many countries in Africa are excluded from global net-zero plans due to a lack of accurate local data and appropriate modeling.

Expanding modern energy access to all in Africa requires models that enable forward-looking decisionmaking to achieve the goals of the people and governments of the region. Building such models requires understanding the challenges inherent in electrifying these countries, including taking a nuanced approach to measuring economic activity, considering special geography and the features of individual nations. Finally, there is a need to reconcile the implicit objective of most global energy system models—decarbonization—with the African continent's need to rapidly ease poverty through economic development.

Using data that are up to the task

Poor energy modeling capacity has already inhibited SSA countries' ambitions. In 2011, the United Nations Secretary-General launched the Sustainable Energy for All Initiative. Since then, 44 African countries have joined, and most have performed a gap analysis, but just 11 have developed an action agenda and investment prospectus. While these plans are commendable, only Kenya and Uganda managed to expand electricity access faster than population growth between 2010 and 2020.

But even in Kenya, efforts to expand access have been hampered by limited data. Although electricity access was previously defined as a grid connection, a closer look shows this definition can downplay significant gaps in electrical service. For example, some parts of Nairobi and some rural areas experience frequent blackouts and changes in voltage, which shut down local businesses and health care centers. Only by installing monitoring equipment and gathering open data can decisionmakers gain an understanding of what infrastructure needs to be installed to fix these problems.

Inability to model market behaviors has prevented other countries from meeting their objectives. Nigeria's Vision 30:30:30, for example, which aims to achieve 30 gigawatts of generation by 2030, with renewable energy contributing 30% of the energy mix, is far behind its targets. As of 2022, the country still had not met the benchmarks for 2017. The financial portfolios of the utilities—including the need to build and maintain excess capacity and the fluctuating fuel costs—were not factored into the planning process. In spring 2022, power companies began to curtail generation because they could not balance their books.

Deficiencies in modeling and data lead to mismatches between investments and outcomes, and between resources and demand.

In general, deficiencies in modeling and data lead to mismatches between investments and outcomes, and between resources and demand. In rural areas where access to electricity is limited, small-scale isolated solar mini-grids might be installed instead of larger, more efficient grid-connected systems, making electricity unaffordable in these areas. By contrast, overestimating how much energy a hydroelectric dam can produce may result in overinvestment and waste. And if the potential for solar or wind power generation is underestimated, it can lead to underinvestment in these sources, squelching opportunities to expand access to clean energy in Africa. Combining sloppy data with poorly conceived models will result in plans that are drastically inadequate for countries that need to develop their economies and energy resources.

Modeling Africa's diverse economies and geographies

The economic metrics used in African countries' energy models require attention to local knowledge and geography. Energy models in industrialized countries use GDP and per capita GDP as driving factors for energy demand. However, in African countries the usual methods of calculating GDP frequently underestimate true economic activity, especially where informal employment is common. The International Labour Organization estimates that 85% of employment in SSA is informal. When Nigeria rebased its GDP in 2013 to include some informal sectors, that measure increased by over 60%, from $270 billion to $510 billion, revealing that Nigeria's economy was larger than that of South Africa's. This implies that models relying on GDP to forecast Nigeria's energy demand before 2014 could have underestimated the country's energy needs, leading to inadequate energy plans.

Another challenge in applying global energy system models to Africa is spatial representation. Today, the 54 sovereign countries in Africa have natural resources, systems of government, and levels of foreign dependency that vary widely. Despite these differences, energy models tend to aggregate African countries into a single region—occasionally with the Middle East—or into several regions. For example, in the Integrated Model to Assess the Global Environment (IMAGE), Africa is represented as five regions: Northern Africa, Western Africa, Eastern Africa, South Africa, and Rest of Southern Africa.

The aggregation masks the substantial heterogeneity among African countries. Over time, as the continent's population is projected to expand from 17% of today's total world population to 40% by 2100, this aggregation may magnify inequalities in data collection and modeling capacity. The Western Africa region in the IMAGE model, for instance, consists of around 25 countries. The population of Nigeria, a single country in that aggregated region, is projected to be larger than the combined population of Canada and the United States (represented in the same model as two separate regions) by 2100. The spatial structure of these models assumes that energy use will remain low, and it does not take into account the very different development trajectories of African countries. These assumptions, in turn, perpetuate bias in scenarios that greatly undervalue future energy demand and emissions, resulting in lower investments.

Lack of country-specific models also hampers planning for changing balances between rural and urban populations and proximity to grid-based power. In some SSA countries, particularly those with lower levels of electricity access, off-grid solutions such as solar home systems, mini-grids, and solar lanterns have helped to improve energy access at the subsistence level. However, many households, given the opportunity, would prefer to be grid-connected because its electricity is cheaper and more reliable and can potentially support larger equipment. With an appropriate local integrated electrification planning framework, decisionmakers could plan for a convergence of off-grid and on-grid services as the grid grows and populations shift. At local and national levels, deployments of off-grid, decentralized, renewable energy systems affect present and future power demand on the grid. Despite this fact, most of the existing energy system modeling studies and plans do not have a comprehensive strategy for grid convergence.

Models for development versus decarbonization

One of the most important distinctions between energy models for industrialized countries and those for developing countries in Africa relates to intent. Industrialized countries must focus on decarbonizing their energy systems. But in Africa, these models must advance socioeconomic development in a carbon-constrained world. To do this, SSA countries must urgently increase energy consumption. Thus, any model mapping energy transition plans for African countries needs to adequately capture how the region's socioeconomic and development priorities influence its future energy trajectories while being faithful to climate commitments.

Many existing energy models assume that the energy trajectory of Africa can be predicted based on Europe's and North America's development narratives. However, this implicit assumption is flawed. Africa's priority is development, and these models often lack inputs relevant to that priority, including income levels, weak infrastructures, fragile institutions, and informal markets. Likewise, decarbonization-focused models that use a country's current per capita greenhouse gas emissions as benchmarks are not appropriate for places where socioeconomic development is an immediate priority.

Even models that do factor in socioeconomic development often assume that electricity access lifts communities out of poverty, but that cannot be taken as a given. Case studies in Nigeria demonstrate that for electrification projects to create meaningful increases in income, they need to consider a community's ability to pay electricity bills, as well as its credit availability and market development. However, few energy models explicitly capture this process, thus creating unrealistic projections for Africa's future energy demand. A 2015 model-based study for Nigeria estimated that a total investment of $34.5 billion could bring electricity access to all in Nigeria by 2030; but the only trade-offs explored were infrastructure and technology, without considering how different financial supports for users would further affect implementation and affordability.

India offers an example of how Africa-focused models might improve. Many extant models use GDP per capita as the primary indicator of development and thus use GDP, combined with population and energy intensity, as a driver of energy demand. In contrast, the Sustainable Alternative Futures for India (SAFARI) model does not use GDP as the main indicator of progress and welfare. Instead, it uses the achievement of developmental goals, along with food, housing, health care, education, power, water, and transportation, to anticipate growth in energy demand. For policymakers, this kind of analytical framework can capture and reflect synergies, while limiting trade-offs among objectives.

Industrialized countries must focus on decarbonizing their energy systems. But in Africa, these models must advance socioeconomic development in a carbon-constrained world.

An action agenda to improve energy modeling for Africa

Currently, there are few Africans in the energy modeling space. A recent study by researchers from the Clean Air Task Force showed that the majority of energy transition studies about Africa are written from afar. Nearly two-thirds of the research was produced without an author based on the African continent. National governments in Africa must build a pool of local experts for their own countries by facilitating partnerships between local academic institutions in Africa and relevant experts from developed countries.

Such partnerships should be used to further build the capacity for data collection. At the moment, SSA nations' statistical offices and energy agencies lack the technological, economic, and human resource capacities to collect, process, and disseminate the required data. Institutions including the World Bank, United Nations, and IEA should improve on their current efforts to provide reliable African data, which many local and international analysts already draw on. But these agencies should also recognize that much important detail is overlooked by regional or continental datasets, and so should support nations to develop the capacity to use local data.

At the same time, African analysts need to embrace new technologies to bridge data gaps. Innovations such as machine learning and artificial intelligence might be used to improve energy modeling studies in Africa by filling in data gaps, improving accuracy, and identifying patterns.

There is also a need for existing African institutions involved in energy modeling and planning to pursue partnerships with various international institutions—establishing regional dialogues, facilitating the exchange of technical advice, and assisting African researchers to learn from best practices in energy modeling globally. One initiative, the Energy Modeling Platform for Africa, already ties together several hundred energy modelers, and it could be scaled up to engage other global platforms. International organizations such as the IEA, IRENA, International Atomic Energy Agency, and International Institute for Applied Systems Analysis, among others, should work with these efforts to promote energy modeling, and energy modelers, in Africa.

Funding remains a significant bottleneck, and there is a great need to build a mixture of funding from governments, international agencies, and the private sector. We believe that overreliance on external financing has limited the capacity of African energy modelers and analysts, as well as the questions that models explore. Self-reliance for funding would give African institutions the leverage to address questions really pertinent to them rather than the questions their funders prioritize. Of course, continued support from international development agencies and financial institutions is necessary, but it should be well targeted and transparent. Just as energy modeling is performed by private sector companies, including utilities, in the United States and Europe, African companies should partner with governments and international organizations to finance energy modeling capacity in Africa.

Bringing funding, expertise, and model development "home" to African countries will advance electrification and development goals, a synergy that should be explicitly recognized. Energy models that draw on expertise from scientists, policy analysts, historians, lawyers, artists, and economists can all help bring Africa-specific features into models. Input from local communities will ensure that energy solutions suit local conditions. This would, in turn, increase buy-in and ownership of energy projects that have resulted from the energy modeling and planning process. One-size-fits-all energy system models will hobble sustainable electrification in Africa. Locally owned, internationally integrated approaches are essential to advance it.

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RECOMMENDED READING

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SYMBIONTS

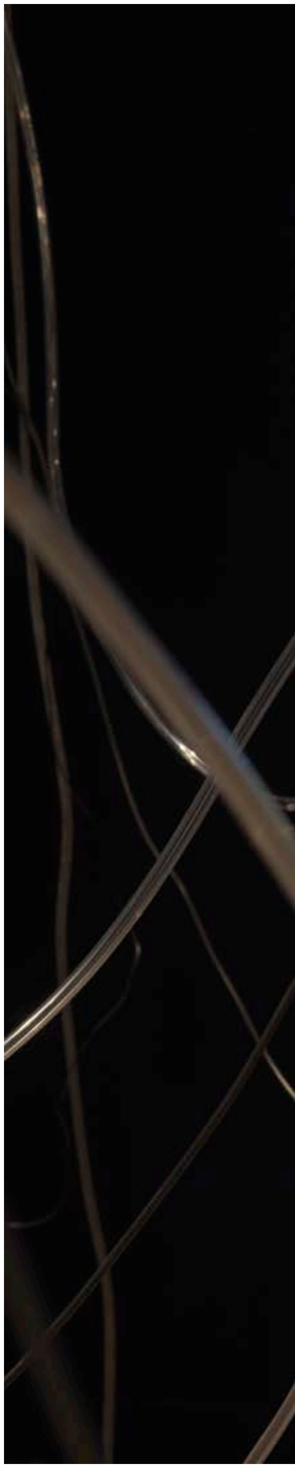
Contemporary Artists and the Biosphere

Symbionts are organisms of different species that thrive through their interdependent relations. Symbionts include mutualists such as the bee and the apple blossom, the commensualist microbes that inhabit our guts and prime our immune systems, and, of course, the parasites that live off other species. What can be learned from these systems in terms of imagining and understanding environmental, aesthetic, and political processes? Recently the MIT List Visual Arts Center hosted an exhibit that brought together over a dozen international artists to explore the idea of symbionts and the inspiration that these systems can offer to imagining a better relationship among biology, design, and society. The exhibit, *Symbionts: Contemporary Artists and the Biosphere*, was curated by Caroline A. Jones, Natalie Bell, and Selby Nimrod, with research assistance by Krista Alba.

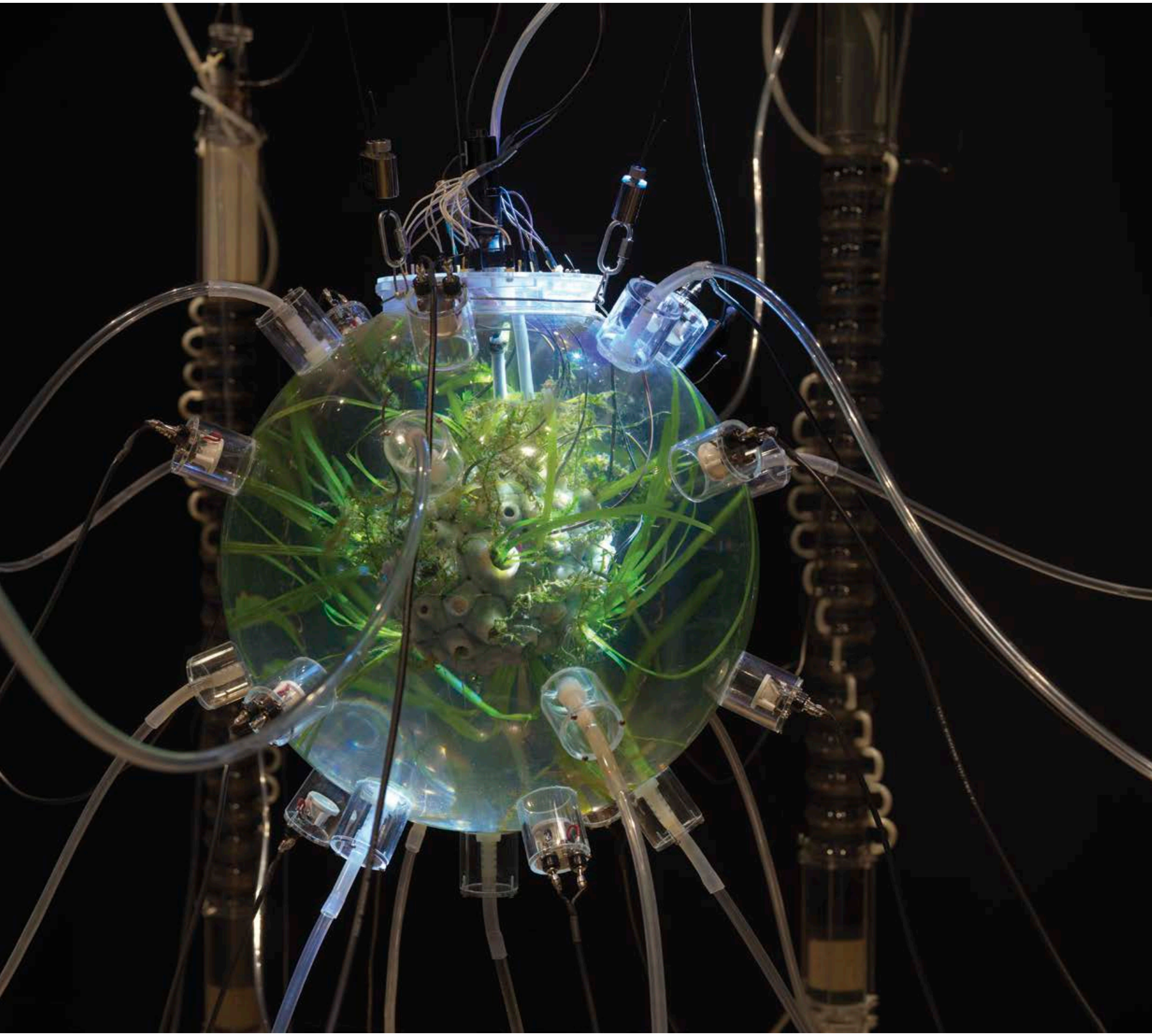
The exhibit represents a new generation of bioartists who are interested in exploring what it means to be interdependent or collaborative within a system. Some of the artists explore living material as partners in the creation of the artwork, while others analyze the tradition of isolating nonhuman lifeforms—and insist instead on emphasizing cohabitation and interdependence.

Images courtesy of MIT List Visual Arts Center.

CANDICE LIN, *Memory (Study #2)*, 2016. Photo by Dario Lasagni.



ANICKA YI, *Living and Dying in the Bacteriacene*, 2019. Courtesy the artist and Gladstone Gallery. Photo by Dario Lasagni.



GILBERTO ESPARZA, *Plantas autofotosinthéticas*, 2013–2014 (detail).
Courtesy the artist. Photo by Dario Lasagni.

(*Top*) MIRIAM SIMUN, *The Sound of a Bumble Bee Refusing to Colonize an Artificial Nest*, 2022. Courtesy the artist. Photo by Dario Lasagni.

(*Bottom*) MIRIAM SIMUN, *The Sound of a Hive Giving Birth*, 2022. Courtesy the artist. Photo by Dario Lasagni.

PAMELA ROSENKRANZ, *She Has No Mouth*, 2017. Sand, fragrance, LED light, light controls, dimensions variable. Courtesy the artist and Sprüth Magers. © Pamela Rosenkranz. Photo by Timo Ohler.

MARY E. MAXON

Racing to Be First to Be Second

A bioeconomy that delivers environmental, economic, and social benefits requires a coordinated regulatory framework.

In laboratories and start-ups across the United States, a new era in biology is already changing the ways in which food, fuel, and materials can be produced. It's not hard to imagine neglected industrial hubs in the American heartland coming to life to produce biobased commodity chemicals from feedstocks grown on nearby farmland, creating jobs and reducing carbon emissions. It's a little harder to imagine over the horizon—where DNA-based data storage becomes a low-energy alternative to server farms, or biobased construction materials modulate temperature and moisture in homes and offices from Alabama to Alaska.

Making these visions a tangible part of American life will require a step change in how society approaches industry. As the authors of "Building a Bottom-Up Bioeconomy" in this journal put it: "Rather than trying to industrialize biology, the real task is biologizing industry." This means breaking with the centralized industrial practices of the past, superseding petroleum-based production processes, and rethinking models of manufacturing success to include regional and local supply chains. It also means changing governance and regulations that were created for the industries and products of the previous century, so that regulators can respond to new opportunities and risks as the bioeconomy evolves over the next one.

Racing to be first to be second

Biotechnology was born in California in the 1970s with the development of recombinant DNA. With federal support it has grown to be a driving force in many economic sectors, including agriculture, energy, and medicine. It generates at least 5% of US gross domestic product, according to the most recent estimates. Globally, the bioeconomy is predicted to be worth $4 trillion per year by the end of the decade.

Historically, biotechnologies in the United States have advanced faster than the laws and regulations that govern them, meaning that regulation can become a bottleneck. In 2012, the Obama administration prepared a National Bioeconomy Blueprint that prioritized creating an efficient regulatory system. The blueprint called for improvements to "reduce barriers, increase the speed and predictability of regulatory processes, and reduce costs while protecting human and environmental health." At that time, it was already clear that federal safety assessment pathways for future products, such as ready-to-cook genetically engineered salmon, lacked clarity and could not serve the more complex regulatory challenges ahead.

However, progress building a new regulatory system has been sluggish. Last year, the President's Council of Advisors on Science and Technology (PCAST) identified "regulatory uncertainty" as one of three key gaps that are slowing the country's progress in advancing the bioeconomy. This uncertainty is a "significant hurdle for companies with novel, complex, and often transformative ideas and products." It can be felt all over the nascent bioeconomy today. At a recent National Academies of Sciences, Engineering, and Medicine (NASEM) workshop on biomanufacturing, one participant described companies "racing to be first to be second" as the approval pathways are often clarified only after a pioneer's innovation triggers a confusing cascade of responses from multiple agencies, costing that first mover time and money—and potentially survival.

Without clear safety assessment pathways for the regulatory decisions that determine whether new products can be marketed, some entrepreneurs have taken promising ideas—including goats that produce milk that may curb diarrhea in children—abroad or abandoned them altogether. Regulatory confusion at this scale can also have a damaging effect on public confidence in both the nascent industry as well as the government's ability to regulate it.

As a scientist and biotechnology advocate who has worked in this space for decades, I am concerned that this failure to create appropriate governance forfeits the opportunity to build the kind of bioeconomy that best serves society. As Debra J. H. Mathews, Rachel Fabi, and Anaeze C. Offodile II have written in *Issues*, a "framework for governance of developing technologies should intentionally drive toward societal benefit, instead of simply hoping it emerges from the market." Creating jobs, a cleaner environment, and other desirable outcomes requires intention and a regulatory process that incentivizes both good products and good manufacturing processes. Today, however, a confusing tangle of legacy rules and agency jurisdictions stymies greater progress for public good.

Trying to build a future on a legacy from 1986

Governance of today's bioeconomy rests on the legacy of decisions made more than three decades ago. Specifically, in 1986, when the US government sought to create a regulatory framework in response to emerging genetic engineering tools, "it retrofitted old laws under a plan called the Coordinated Framework for the Regulation of Biotechnology," according to futurist Amy Webb and geneticist Andrew Hessel, instead of crafting new laws to govern genetically engineered products. Statutes written decades before genetic engineering became possible were reinterpreted to accommodate the regulation of new technologies that were then in their infancy.

This overall approach resulted in a decentralized regulatory process that relies on agencies coordinating themselves via a voluntary framework. The coordinated framework tasks three primary agencies—the Environmental Protection Agency (EPA), the Food and Drug Administration (FDA), and the Department of Agriculture's (USDA) Animal and Plant Health Inspection Service (APHIS)—with regulating the products of biotechnology.

In addition to the three key agencies, other federal regulatory agencies and offices are also tasked with the oversight of certain products of biotechnology, including the USDA's Food Safety Inspection Service, the Department of the Interior's Fish and Wildlife Service, the Commerce Department's National Oceanic and Atmospheric Administration, and the Department of Labor's Occupational Safety and Health Administration. The result for developers of new types of products is often confusion, lack of coordination, and ambiguous jurisdiction.

In 2017, NASEM sounded a warning regarding the lack of regulatory transparency. Its report, *Preparing for Future Products of Biotechnology*, observed that "public confidence in government oversight of emerging technologies may be eroded" in the absence of mechanisms that provide clarity and transparency for how the regulatory process is conducted.

That same year, the EPA, FDA, and USDA updated the coordinated framework. The update provided an outline of regulations that may apply to biotechnology products and guidance to navigate the regulatory process within each agency. However, the framework lacks guidelines to help companies determine which agency or agencies have jurisdiction over their product or its components. And even so, agency roles and responsibilities can remain ambiguous.

Federal oversight of genetically engineered and, more recently, genome-edited crops and animals illustrates the unintended consequences of a decentralized regulatory process that depends on "regulatory triggers" as defined by each agency's statutory remit. Sometimes more than one of the three regulatory agencies has oversight, for different reasons, for a single product.

The coordinated framework requires, for example, that USDA's APHIS decides whether a crop should or should not be regulated under the Plant Protection Act. If APHIS determines that the crop does not pose a plant-pest risk, USDA requires no further oversight. However, if that crop contains a biopesticide or "plant-incorporated protectant," a second regulatory agency, the EPA, is tasked with reviewing only the pesticidal protein and gene under the Federal Insecticide, Fungicide, and Rodenticide Act and the Federal Food, Drug, and Cosmetic Act. The EPA does not review the crop itself—only whether the available data demonstrate that the biopesticide component does not pose unreasonable risks to human health, nontarget organisms, and the environment. A third regulatory agency, the FDA and its Center for Food Safety and Applied Nutrition, then engages in a voluntary consultation with the manufacturer to determine whether the agency has any further questions regarding the manufacturer's assessment of the crop's food safety. For innovators attempting to bring their products to market, this can add years to the approval process.

The case of two lab-grown mosquitos

This perplexing system can have a chilling effect on bringing a product from the lab to market, and it can privilege market entrants that happen to choose one pathway arbitrarily over another. A case in point can be seen in the differing experiences of two novel mosquito control methods, Oxitec and MosquitoMate, as they went through the regulatory process.

Both treatments involved the development of mosquitos grown in labs, and both were designed to slow the transmission of mosquito-borne diseases such as malaria, dengue, and Zika by reducing mosquito populations. And both products presented the US regulatory system with a type of product that it had not encountered before. However, Oxitec had developed its mosquito with genetic engineering, while MosquitoMate did not: its mosquito was infected with a bacteria called *Wolbachia*. An article in *Pathogens and Global Health* described the very different regulatory pathways that the two products encountered.

Although both products used altered mosquitos whose impact outside the lab could not be fully known, they met different regulatory fates. Using an established path for the testing of pesticides, it took MosquitoMate approximately six years to be reviewed, tested, and approved for market by the

EPA. In contrast, for nearly 10 years, the Oxitec product went from the USDA, to FDA, to EPA before Oxitec withdrew its application.

The authors write that compared to MosquitoMate's relatively straightforward path to approval, Oxitec's "decade-long struggle to field test OX513A demonstrates the complexity, unpredictability, and opacity of current technology governance." In particular, the authors noted, this governance system, which lacks methods to adequately gather public input, is "ill-equipped to manage controversy."

Moving innovation out of labs and into the world

If the United States is to realize the ambitions of President Biden's new National Biotechnology and Biomanufacturing Initiative to expand domestic biomanufacturing and foster innovation across the nation, action is needed to develop a transparent, fully staffed regulatory system that is prepared for future products of biotechnology. Without that, many discoveries will remain mainly in laboratories and fail to advance a more sustainable economy.

After the 2017 *Preparing for Future Products of Biotechnology* report, which was sponsored by the FDA, USDA, and EPA, NASEM published *Safeguarding the Bioeconomy* in 2020, funded by the Office of the Director of National Intelligence. In October 2021, the philanthropic initiative Schmidt Futures, where I work, convened a special task force to inform a report called *The US Bioeconomy: Charting a Course for a Resilient and Competitive Future*. All three reports converged on a set of actions to streamline the regulatory process, improve interagency communication, and fund and train agencies so that they can anticipate future products of biotechnology.

There are several approaches that could help in the short term. For example, setting a deadline of, say, 90 days after submission to designate a lead agency for each product's regulatory review would make the process more efficient for applicants to navigate. Another improvement would be to enable agencies to assess risks in parallel rather than sequentially, so that review processes do not drag on as long as they did with Oxitec.

Another possible strategy for agencies is the use of enforcement discretion when a new product is considered low risk. For example, the FDA recently made its first enforcement discretion decision for "slick-haired," genome-edited beef cattle, determining that the edit did not raise any safety concerns. This strategy may permit developers to bring technology products to market more efficiently without compromising animal or human safety. And as long as the decisionmaking process is transparent and can adequately integrate public input, it can also build public trust.

Finally, agencies are under-resourced and lack both funding and staff to prepare for the proliferation of new products now and in the future. There is an immediate need to prepare a new cohort of experts to scan the horizon for future biotechnology products, especially for those that are the first of their kind. There will also be a need for technical advice on the data that agencies will need to evaluate regulatory approval applications for products of emerging biotechnologies. Meeting these needs will require a multidisciplinary, targeted training program for regulatory staff involved in oversight and commercialization of emerging biotechnology products.

Biocoordination

In the short term, the highest priority issues for the agencies to address are communication and collaboration among themselves. The CHIPS and Science Act of 2022 mandates the formation of a National Engineering Biology Research and Development Initiative to be supported by an Initiative Coordination Office (ICO). This ICO could support and coordinate the National Biomanufacturing and Biotechnology Initiative.

This bioeconomy ICO—if established by the White House Office of Science and Technology Policy—could facilitate interagency collaboration, cross-train regulators, and provide for needed horizon-scanning. The bioeconomy ICO could coordinate training opportunities for regulators and facilitate an information network to link regulators with industry, academia, and others relevant to the bioeconomy and its products. The ICO could also coordinate regular agency collaboration on horizon-scanning for future products of biotechnology, and it could work to establish a single point of entry for biotechnology products through which product developers could enter and be guided through the regulatory system. These last two actions alone could address two important bottlenecks in the current system.

To tackle the thorny problem of improving trust in the regulatory process, the federal government could convene a commission—bringing together experts from industry, government, and academia—to inform updates to regulatory statutes that better reflect modern biotechnologies. This kind of forum would be the ideal space to tackle the complexities of the pre-commercialization phase, which require a delicate balance for regulators between transparent decisionmaking and confidentiality obligations.

Concerted and deliberate policy action will be required to turn today's nascent biomanufacturing industry into a dynamic engine of growth and sustainability. From where we stand now, it's hard to anticipate precisely how this technology may transform the economy, the environment, and American life. Surely, the process will require a twenty-first-century governance and regulatory framework that can simultaneously manage complex data-based decisions and foster public trust as the sector evolves.

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DAVID R. GILLUM

The Making of a Biosafety Officer

Understanding how biosafety professionals generate knowledge on the job can help train skilled personnel and craft rules to keep communities safe.

The potential risks for accidents and misuse increase as biotechnology becomes more sophisticated, less expensive, and increasingly distributed. During my 28 years as a biosafety officer, I have dealt with laboratory explosions, fires, spills, needlesticks, eye contamination, accidental releases, and lost or unaccounted-for inventory—along with the day-to-day anxieties of keeping labs safe. Biosafety professionals are responsible for mitigating risks at universities, federal laboratories, health care facilities, nonprofits, and pharmaceutical and other commercial operations. While we—I am one of only a few thousand in the United States—have similar job titles, our backgrounds run the gamut from microbiology to chemistry, from high school or associate degrees to PhDs.

We are so diverse that it raises the question of how people become biosafety professionals and what makes them proficient. I will attempt to answer that question by looking at my own career, which has been characterized by the acquisition of what the late British epistemologist Michael Polanyi characterized as "tacit knowledge," picked up here and there, both situationally and systematically, over nearly three decades. This learning process has bearing on the laws, regulations, policies, standard operating procedures, and written documents that govern biosafety; implementing those requires proficiency, and that is gained chiefly through on-the-job experiences plus extramural work that spans institutions and contexts. It is *in the doing* that regulations on pieces of paper become realized in the world.

The question of how the biosafety community generates and transmits knowledge is interesting in itself, but it is also an urgent issue. The need for biosafety workers is growing just as current professionals are skewing older: an estimated 54% are over 50 and one of the few surveys of the field suggests there are six times as many biosafety officers over 70 as there are under 30. Preparing more of us—and keeping the public safe as the complexity of biological research, health, and manufacturing projects burgeons—is made more difficult by the importance of tacit knowledge in our education. Methods for understanding, communicating, and mitigating risk are difficult to transfer to others. To enhance public health and safety, people in my line of work should ease this transfer by considering how the profession might be standardized and formalized.

The question of how the community educates itself is also pressing because it is inextricably connected to how written rules of biosafety are carried out. It is through their translation—from paper edicts to institutional culture and to individual practice—that the public has been protected as biological experimentation evolved between 1976 (when the National Institutes of Health released its first guidelines on recombinant DNA) and 2023. The accumulated tacit knowledge of the country's biosafety officers forms a web of precaution that picks up where rules leave off.

Today, those rules are being reconsidered. In January 2023, the US National Science Advisory Board for Biosecurity (NSABB) issued the Proposed Biosecurity Oversight Framework for the Future of Science. In response to President Biden's Executive Order on Advancing Biotechnology and Biomanufacturing Innovation for a Sustainable, Safe, and Secure American Bioeconomy, federal agencies are now considering multiple new schemes to support biosecurity. Examining how the country's biosafety officers have accumulated their knowledge could help formulate policies that are proactive and protective, rather than merely performative.

One day after Christmas

Over a biosafety career, on-the-job training forms a series of vividly remembered moments characterized by emergency, anxiety, and learning, which shape my approach to the job on a daily basis. In late December 2009, when I was the biological and chemical safety officer at the University of New Hampshire, the campus veterinarian called to say that a local 24-year-old woman had been diagnosed with gastrointestinal anthrax. The cause was unknown and state agencies investigating were joined by the Centers for Disease Control, the Federal Bureau of Investigation (FBI), and the Environmental Protection Agency (EPA), as well as other federal entities. Among the federal regulations for biosafety, the one known as 42 CFR 73—which governs the handling of potentially dangerous pathogens and certain toxins, called "select agents"—has very specific guidelines for inventory control. The veterinarian said our file manager for the Federal Select Agent Program at the Department of Health and Human Services (DHHS) had requested that we conduct an inventory to determine whether the campus's samples of anthrax had been improperly accessed.

The campus was cold and deserted when the veterinarian and I met at the lab. We were both on edge, worried about what we might find. At that point I had been working in biosafety for more than 15 years, and I couldn't help but be reminded of the anthrax mailings of 2001, which were followed by nearly a decade of investigation that initially focused on scientists. We put on laboratory coats, N95 respirators, nitrile gloves, and safety glasses, located the freezer key in its lockbox, and entered the necessary information into the logbook. After locating the cryogenic freezer boxes with the anthrax vials, we moved them to the biological safety cabinet and began to inventory each one. Our anxiety was suffused in a routine of familiar and highly proscribed procedures. Fortunately, we accounted for all vials.

A few days later, we heard that the patient had been exposed to anthrax in the campus ministry building while dancing as part of a drum circle. A team from the EPA and FBI had discovered that some of the drums used hides that had not been treated before they were imported to the United States. They believed that the drumming caused the anthrax spores to become airborne, exposing the individual. No one else became infected.

But once the mystery was solved, the public's concerns increased, creating the need for new capacities and procedures for which there were no prewritten specifications. Drum owners around town began to worry about whether they were being exposed to anthrax. The university requested that my team accept drums at our hazardous waste facility. We quickly determined that it was not large enough for the instruments that were coming in. Over the next 48 hours, we worked with the facilities management department to construct a metal fence in a parking lot where concerned citizens could easily and safely drop off their drums. Soon cars began to arrive, and people threw their drums, often wrapped in garbage bags, over the fence.

For me, experiences like this were very stressful, but I learned about emergency management and public response, how to engage with multiple federal agencies, and how to draw on my own and colleagues' professionalism to cultivate an atmosphere of competence and calm. I also learned how to safely accept a pile of potentially hazardous drums in a parking lot. It would not have been possible to learn this from a book.

Static rules, dynamic knowledge

As the anthrax example demonstrates, Polanyi's distinction between "explicit knowledge" (i.e., knowledge that can be explained and transmitted to others) and "tacit knowledge" (i.e., knowledge that is composed of individual experiences) is highly relevant to biosafety. There are no simple knowledge databases that explain how to mitigate biological risk in experiments—never mind how to keep up with rapidly changing situations like an anthrax scare. Knowledge is gained from site-specific experiences, working side-by-side with others, understanding the processes and operations of different facilities, and having a sense of how enforcement of biosafety regulations and policies has evolved over time in response to new needs.

The rules themselves have remained relatively static. Over the past 50 years, five significant biosafety governance systems have been implemented in the United States to regulate biological research. In 1976 the National Institutes of Health released its Guidelines for Research Involving Recombinant or Synthetic Nucleic Acid Molecules, and in 1991 the Occupational Safety and Health Administration released the Bloodborne Pathogens Standard in response to health care workers who were becoming ill with HIV and hepatitis from needlesticks. After 9/11, DHHS began the Federal Select Agent Program in 2002. Finally, the Policy for Institutional Oversight of Life Sciences Dual Use Research of Concern was instituted in 2014 and the Recommended Policy Guidance for Departmental Development of Review Mechanisms for Potential Pandemic Pathogen Care in 2017.

These rules provide a framework for oversight, but they do not explicitly describe how to conduct biosafety or provide mechanisms to ensure compliance. Out of the five, only two have penalties for and procedures to determine criminal culpability: the ones covering bloodborne pathogens and select agents. The others are considered government funding policies, meaning the recipients of federal funds must create an Institutional

Biosafety Committee (IBC) to review relevant research on recombinant or synthetic DNA or RNA, or an Institutional Review Entity to review dual use work (research that could be harnessed for both benevolent or malicious purposes). But pathogenic experiments that don't involve these molecules—such as research with non-recombinant Ebola, avian influenza, or coronavirus—would not require an IBC review. Furthermore, noncompliance with the policies themselves does not always result in a loss of government funding. Thus, the management of biological risk in the United States primarily comes in the form of self-governance by the scientific community.

Biosafety remains informally organized, with neither formal degrees nor well-defined pathways leading to a career. A 2018 survey of American Biological Safety Association members found that nearly 50% had degrees in microbiology; other members held degrees in environmental health, public health, chemistry, infectious disease, industrial hygiene, engineering, occupational health, medicine, veterinary sciences, first response, security, and architecture. Roughly a third listed "other" as their major field of study.

In larger institutions, the biosafety officer is generally a full-time staff member. In smaller institutions, the officer may be a researcher, laboratory member, or a member of the environmental health and safety team. The National Institutes of Health's 1979 *Laboratory Safety Monograph*, which was one of the first to describe the role, provided this guidance when selecting the biosafety officer:

> The principal function of the biological safety officer should be to advise the principal investigator, the IBC, and the laboratory worker concerning the most appropriate safety practice that will assure the safe conduct of recombinant DNA research. Depending on the nature and extent of the institution's recombinant DNA programs, the biological safety officer may be a full-time position, or the duties may be assigned to an individual who has other responsibilities. Where the institution has a comprehensive environmental health and safety program that includes expertise in biological safety, it would be useful to select the individual from the program's professional staff.

This early emphasis on selection, rather than training, now means that the majority of biosafety knowledge is learned on the job, with little official pedagogy or academic coursework. For years, the field has debated whether biosafety experience outweighs biosafety certification or credentialing. Advocates for the former argue that experience is essential to understand the complexities of biosafety programs. Credentialing advocates argue that someone is not fully competent until they can pass a test and obtain a formal certification.

Further complicating the acquisition and transfer of knowledge, biosafety professionals themselves must balance what to share with others and what to keep secret. For example, acknowledging that an institution has a high-containment laboratory is usually fine; however, sharing how to access the lab is not. Some biosafety officers even refuse to share secrets with others in the profession, often out of a concern they could be viewed as failing to do their jobs appropriately or worries that they would be fired if their organization received negative media coverage.

Becoming a biosafety professional

Like most people in my profession, I never set out to become a biosafety officer. In 1998, when I was a graduate student in the environmental health sciences program at the University of Massachusetts Amherst, expecting to earn my degree and then go work for a pharmaceutical company or government lab, I got a side job researching biological safety manuals, exposure control plans, and standardized biosafety inspection checklists from other universities for the school's biosafety officer.

As part of my graduate studies, I took a class with the biosafety officer, where I was formally introduced to the politics of safety in an academic environment. We learned, for example, that there was a difference between who had the authority to shut down a laboratory *in theory* and who could do it *in practice*. We also discussed how to leverage the IBC to ensure a decision was not perceived as coming from a single person, and how tenured professors were often given more leniency than nontenured faculty and staff. This formal academic training gave me insight into the politics of how safety organizations worked in a large university and some perspective on how a person might accomplish the job under those unique conditions.

At the time, biosafety professionals assumed that changes in our responsibilities would come from changing biological capabilities—that is, through innovation—but history intervened: the next big change occurred in the rules themselves. On September 11, 2001, I had a full-time job in environmental health and safety at the Harvard University Longwood Medical School and was working in a safety office in the basement of the university's Institutes of Medicine. A week later, the first letters containing anthrax were mailed in the United States. With everyone on high alert, I was tasked with creating a presentation for campus employees on how to handle mail. The only guidance available then came from the United States Postal Service, and it included a review of how to use latex gloves and an N95 respirator, how to identify and categorize suspicious mail, and what to do if someone found it. Although I had guidance from the school's biosafety officer, we all had to think on the fly to create procedures to deal with new situations.

Soon enough there were new rules, but they too had to be interpreted. In late October 2001, Congress issued the USA Patriot Act, expanding the previous Biological Weapons Statute to include restrictions on who could possess or use certain biological agents and toxins. For the first six months after passage, it was unclear who would be accountable, how exemptions would be determined, how the university would gather the necessary information, and how the rules would affect those currently working with the materials. In this vacuum, I was tasked with reading the regulations and developing a summary of how it might impact the university.

In April 2002, when I started working for the University of New Hampshire (UNH) as the biological and chemical safety officer, the rules were still murky. To continue my education and strengthen my network, I joined an email listserv, signed up for a biosafety course, and enrolled in the American Biological Safety Association. The listserv became very active when DHHS issued their Preliminary Guidance for Notification of Possession of Select Agents in the Federal Register on July 12, 2002, and biosafety professionals across the country began to grapple with its implications.

Over a biosafety career, on-the-job training forms a series of vividly remembered moments characterized by emergency, anxiety, and learning.

The first thing institutions needed to do was assess whether they possessed any of this newly identified category of biological material: select agents. This was a remarkable moment of realization, as biosafety officers across the country needed to ask researchers and staff to go through freezers to see what they could find. There was no central repository of information, no library or clearinghouse. In order to have the knowledge, we had to create it. Suddenly, many different types and strains of select agents were reported on UNH's campus, such as *Bacillus anthracis* (anthrax), *Franciscella tularensis* (tularemia), *Yersinia pestis* (plague), conotoxin, ricin, tetrodotoxin, and shiga-like toxin. If we had not bothered to ask people to make inventories, we may never have known these materials were present on campus. This is a classic example of biosafety's unique relationship to knowledge: it must be constantly created at the junction between rules, human behavior, facilities, and microbes.

Consider the knowledge needed to maintain safe operations in a laboratory. To learn the intricacies of the electrical, plumbing, networking, and access control systems of UNH's biosafety level 3 high-containment facility used to study anthrax and plague, I reviewed building floor plans, met with the building manager, and worked with information technology staff to install card- and pin-access door locks and to review cybersecurity systems for computers, printers, and telephones. I then spent countless hours talking with people who understood all the details of how the facility interacted with other campus systems, including how steam pipes connected to the autoclave, how to make sure the laboratory sink drains captured the wastewater influent so it could be disinfected prior to entering the sewer system, and which motors in the penthouse needed to be kept on emergency power to keep the facility under negative air pressure in an electrical outage.

The knowledge I gained was essential for in-the-moment snarls and complications that could have had dangerous implications. My familiarity with the plumbing of the autoclave meant I knew to turn off the steam quickly when a pipe burst in the ceiling. And when a drain elsewhere in the building clogged, I could track it back to that same autoclave, where an absent-minded researcher had probably used a plastic container that melted. And it wasn't just information specific to this institution, or even this laboratory, that I needed to learn from other people within the system. I also needed to be able to find resources outside the system. When New Hampshire had an ice storm that led to a week-long power outage, I called around to grocery stores to find dry ice that we could put into the -80°C freezer so the anthrax and plague samples wouldn't go bad.

In another instance demonstrating the complexities of tacit knowledge for biosafety officers, UNH information technology personnel didn't want to go through the extensive background checks needed to access high-containment facilities. It fell to me to learn how to change the batteries when the battery-powered locks stopped working, reprogram them, and then ensure that everyone had the updated codes and electronic cards to access the lab.

These examples could have occurred in any of the last several decades, but the arrival of the federal select agent regulations in 2002 was a definitive moment for the life sciences. The regulations restricted who could perform research with listed biological materials and increased security measures, requiring background checks for individuals and prohibitions on using any controlled substances (including marijuana) by lab personnel and others with access to the agents. I had to inform colleagues in the microbiology department that they could no longer participate in the Federal Select Agent Program because of their nationality. Like many in the field, I felt this was unjust. I documented the many researchers who chose to destroy their biological materials and stop their work rather than comply with the new requirements. Without these experiences early in my professional journey, I may never have understood how certain aspects of biosafety are enacted before their importance or impact is fully understood. Just as it is important to appropriately transfer biosafety knowledge so officers can gauge diverse risks and hazards within an institution, it is also important to consider the risks of new controls on society at large.

Biosafety workers must develop the understanding that information is usually incomplete, perhaps because the right questions have not been asked. It takes experience to know what is not there. When I was managing a review committee, a researcher failed to report a portion of their plague research on the forms to register their activities. Only during questioning did the missing information come to light. Without it, the committee would not have been able to make informed, risk-based assessments. It is even more difficult to find knowledge that is concealed, whether through ignorance, laziness, or actual malice. Unfortunately, this is one of the weaknesses of self-regulating IBCs: they are only as good as the quality of the information provided to them.

And because of these larger security concerns, there is also knowledge that cannot be shared, even among people working in biosafety. Many of us working with security clearances are likely very familiar with not sharing certain kinds of information. Similarly, there are also forms of knowledge that may remain hidden indefinitely.

Integrating tacit knowledge into rulemaking and training

In retrospect, my career might be viewed as an ongoing 28-year experiment in how to keep lab workers, the community, animals, and the ecosystem safe. This experience offers guidance in considering how to make and enforce rules in the face of rapidly changing technology.

First, biosafety professionals' knowledge should be incorporated into the rulemaking process. The tacit knowledge that is essential to enforcing rules could be valuable as new rules are written. Currently, biosafety professionals submit extensive comments on proposed rules during public comment periods. I have personally submitted dozens of comments. But the unique perspective offered by biosafety officers should be more formally recognized by, for example, including them as stakeholders on the committees involved in the government rulemaking process.

Second, the idea that biosafety can be enforced by a small, aging crowd of specialists is rapidly becoming outdated as bioscience experimentation evolves. The basics of biosafety must be a part of the education of everyone conducting life sciences research, as well as anyone interested in the subject. Principles of biosafety should be brought into elementary, secondary, and postsecondary classes and syllabi, textbooks, seminars, and webinars. It should be reinforced through innovative board or video games that teach the importance of biosafety and help students develop the sort of systemic thinking and problem-solving skills needed for effective biosafety.

What this guidance reflects is a shift in emphasis within biosafety from after-the-fact mitigation to proactive and rigorously data-based risk management. To maintain safe practices as the biosciences expand, the field needs to embrace a culture of ongoing experimentation, collaboration, and information sharing. Data and best practices about risk mitigation should be compiled, correlated, and freely shared through biosafety networking platforms and regular publications. The success of these activities will benefit from the involvement of interdisciplinary scholars who can help identify the processes that generate knowledge as well as those that require more research.

Biosafety professionals will likely always require on-the-job training to understand the scope and moral obligations of their role. Creating a formal, explicit component of biosafety training, however, could significantly speed up and strengthen the process. Key to this would be documenting biosafety knowledge and making it accessible for new officers to synthesize. Engaging biosafety professionals in research of their own processes could help to build empirical data and educate relevant personnel and scientists with oversight responsibilities for research involving agents that could be used as biological weapons or spur a future pandemic.

Finally, additional research is needed to appreciate who has a voice in the biosafety field and who does not, and why. This would help with improving biosafety tacit knowledge and recognizing what makes someone a credible authority in the field. My research here only focuses on my own personal and professional experiences, and there is significant room for other voices to be heard, discussed, and valued.

In *Personal Knowledge,* Polanyi wrote, "I have shown that into every act of knowing there enters a passionate contribution of the person knowing what is being known, and that this coefficient is no mere imperfection but a vital component of his knowledge." Recognizing "the act of knowing"—in all its imperfect complexity—is essential to building a future of safe biological research.

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ANTONY SCHWARTZ, ANDREA VOGEL, AND MARY BROCK

Biosafety Needs to Redefine Itself as a Science

An expansion of today's static definition of biosafety to include research for mitigating risk will advance both science and public safety.

Have you heard the joke about jobs in biosafety? One professional asks another for recommendations to fill an open position. The second says sure, but she first needs recommendations to fill her three open jobs! It's not really a joke: a recent newsletter for biosafety professionals carried multiple job openings from the most senior to the most junior positions. After three years of a pandemic plus the dawn of relatively easy gene-editing and other advances in biotechnology, demand for biosafety workers is rising. But we argue that the worker shortage also stems from a more fundamental issue: biosafety is seen mainly as a compliance issue, not a science.

In an executive order signed in September 2022, President Biden set forth the goal to "elevate biological risk management" as part of a broader effort to advance biotechnology and biomanufacturing. The order specifically noted that the administration's efforts should include "providing for research and investment in applied biosafety and biosecurity innovation." This marks a rare opportunity to nail down a definition of biosafety so that it is established as more than a set of guidelines to be implemented.

Yes, biosafety professionals oversee compliance with regulations, but they also address problems that demand empirical research. Biosafety should be recognized as a hard science of risk management and innovation that requires formal training. Such a change will make for more efficient, improved safety processes as well as encourage better training and greater interest in biosafety as a career. Without this definition, the progress of life sciences research will be hampered by a lack of safety officers and outdated, inflexible practices.

Risk assessment is already at the core of most biosafety professionals' daily work. Some hazards can indeed be mitigated with standardized practices and procedures. However, most circumstances require careful study of the biohazards, the procedures performed, the equipment used, and the mitigation measures available (facilities, containment devices, or personal protective equipment, for instance). Establishing biosafety as an innovative research discipline will enable the field to keep pace with a sector that is going through momentous changes.

None of the definitions of biosafety put forward so far capture the complex, dynamic nature of the discipline. We propose the following: "Biosafety is the study of biological hazards using evidence-based risk-assessment and mitigation measures to prevent accidental exposure to a biological hazard or release to the environment."

Static non-status

Biosafety professionals have been meeting informally since the 1950s. The US Centers for Disease Control and Prevention (CDC) and National Institutes of Health (NIH) joined the gatherings in the 1960s. In those early days, the focus was on regulation and classification. In the 1970s, the four biosafety level designations were established, as were regulations on shipping microorganisms and toxins. Starting in 1984, the CDC and NIH published the *Biosafety in Microbiological and Biomedical Laboratories*, a manual known colloquially as the biosafety bible. The current edition refers to biosafety as merely "the mechanism for addressing the safe handling and containment of infectious microorganisms and hazardous biological materials."

The World Health Organization's *Laboratory Biosafety Manual*, another set of guidelines, defines biosafety as "Containment principles, technologies, and practices that are implemented to prevent unintentional exposure to biological agents or their inadvertent release." These and other descriptions convey biosafety almost passively, as a set of practices to be followed. None acknowledge biosafety as a process of risk assessment that informs risk mitigation strategies.

Given this background, it is perhaps not surprising that many biosafety professionals don't consider their creativity in day-to-day work as innovation or evidence collection. For example, we have been to workshops, nationally and internationally, where colleagues have described doing systematic assessments of waste decontamination of infectious agents with limited resources—not realizing that this is in fact applied research.

Without recognition of the science behind biosafety, such innovative work may not be supported by the institutions where potentially risky experiments are carried out or the funders that underwrite such experiments. Securing time, funding, and other resources to gain knowledge to keep scientists and the public safe can be difficult. As biosafety's scope has grown, practitioners need to formally establish biosafety as its own distinct field of scientific study worthy of funding, with robust infrastructure to support rigorous inquiry.

Here's an example of a useful biosafety investigation with no obvious source of support: lentiviruses—which cause a number of human and animal diseases, including AIDS—have a place in laboratories worldwide as a useful tool for transferring genes into cultured cells. Conventional wisdom assumes that all lentiviral vectors (i.e., the particles that carry the DNA sequences) are taken up by the cultured cells within 72 hours, thus requiring fewer safety precautions thereafter. But further assessments are needed to know if this is indeed the case for various gene inserts, CRISPR modifications, and other advances.

Here's another example: autoclaving is a common technique for sterilizing samples when they are no longer needed. It's used to decontaminate viruses, bacteria, fungi, and other potential infectious agents. Studies that determine optimal autoclaving times for various growth media, freezer temperatures, and container sizes could make a routine process shorter and less complicated while still maintaining safety.

Expanding biosafety to mean "the study of biohazards" will inculcate a mindset of continuous experimentation and discovery that will advance the field—and advance research safety overall. There are precedents for defining or redefining a discipline to influence the direction of the field. Nursing is an example of a discipline that reoriented itself from following rote procedures to embracing a mission—patients' health—while advancing knowledge through empirical research. Public health is also an apt example. Over a hundred years ago, one of the founders of the field, C.-E. A. Winslow, defined it as "the science and the art of preventing disease, prolonging life, and promoting physical health and efficiency through organized community efforts." Definitions like this encourage a broad range of ongoing inquiry and enable a field to secure the funding necessary for conducting research. In biosafety, the lack of such recognition contributes to a dearth of training, qualified personnel, and research support.

Expanding biosafety to mean "the study of biohazards" will inculcate a mindset of continuous experimentation and discovery that will advance the field—and advance research safety overall.

Time and again, biosafety professionals conduct their own research to gather the data needed to make evidence-based recommendations. Official biosafety manuals should formally endorse this in their next updates, and efforts building off the Biden administration's executive order should explicitly seek to advance research capacity in biosafety.

The basic components necessary to define biosafety as the study of biohazards are already ingrained in the field's practice. A definition that reflects this fact can propel the profession and better support the advanced biotechnology and biomanufacturing sectors that rely on it.

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DOMINIQUE A. TOBBELL

The Transformation of American Nursing

In the decades after World War II, nurse educators built a science of nursing. Their work underpins the profession as it is practiced today—and offers insights for other disciplines into how knowledge is created, valued, and used.

Nursing faced a crisis in the years following World War II. The arrival of new technologies, potent pharmaceuticals, and complex surgeries had made patient care increasingly complex. The regimented, procedure-based training of hospital-based diploma programs that had predominated in nursing education before the war became inadequate. Nurses often found themselves without the availability, knowledge, or authority to provide appropriate care to critically ill or dying patients.

Studies conducted in the late 1940s and early 1950s documented the crisis in hospital nursing and predicted that it was necessary to graduate between 50,000 and 75,000 new nurses each year. But rather than tackle discriminatory hiring practices, salaries, or working conditions—issues that might have improved job satisfaction and thus expanded retention—nurse leaders, hospital administrators, and other health care authorities focused on how to produce more nurses by expanding and reforming nursing education.

In particular, nurse educators sought to establish nursing as an academic discipline. Beginning in the 1950s, they introduced bachelor of science in nursing (BSN) programs on university and colleges campuses. This new model of undergraduate nursing education emphasized science-based learning, clinical thinking, and patient-centered practice. It prepared nurses for their new role as an "expert and an independent practitioner," in the words of nursing theorist Virginia Henderson. By emphasizing a health perspective rather than a disease perspective, by considering patients holistically, and by prioritizing the agency of patients in shaping their health, nursing and its science sought to stand apart from the reductionist model of medicine that emphasized disease, diagnosis, and cure.

By the 1960s, nurses who had undergone advanced clinical training at the master's degree level assumed new advanced specialty practice roles in areas that included psychiatric nursing, maternal-child health, oncology, nephrology, and critical care nursing. Nursing's academic project also entailed creating and demarcating the boundaries of a distinct science of nursing. Nursing PhD programs were established to prepare generations of nurse scientists able to conduct the clinical research necessary to improve patient care.

As nursing embarked on this academic project, it faced a series of issues and challenges. Two of these challenges proved especially determinative in shaping today's nursing education and practice. First, how would nurses construct their discipline? That is, what types of knowledge and research questions would they focus on, and which research methods and theoretical frameworks would they draw upon? Second, as nursing committed to making the academic preparation of nurses more rigorous, how would the profession maintain accessible pathways into nursing for students from underserved and historically marginalized communities?

Tim Okamura, *Nurse Tamika*, 2021, oil on wood panel, 24 x 30 in.

Building the discipline

From the late 1950s through the early 1980s, academic nurses constructed a science of nursing that would provide the basis of nursing practice. They did so not only to improve patient care, but also to secure their roles within the postwar research university. Nursing science was to be distinct from, yet complementary to, the biomedical science that underpinned medical practice and research, particularly its focus on the identification, diagnosis, and treatment of discrete diseases. By contrast, nursing—and the science that informed it—would move beyond "merely … treating disease entities," as sociologist Frances Cooke Macgregor wrote, to treating "patients as 'total persons.'" By establishing nursing science as an interdisciplinary science that integrated psychological, cultural, social, and physiological understandings of health, illness, and the patient, nurses could claim distinctive knowledge, skills, and expertise. This expertise was rooted in an understanding of patient behavior and attitudes by which nurses would contribute to the improvement of patient care.

But nurses grappled with how to distinguish nursing science from the theory and knowledge of the disciplines it drew upon. During the 1950s, 1960s, and 1970s, a small group of nurse theorists, including Rosemary Ellis, Virginia Henderson, Dorothy Johnson, Hildegard Peplau, Martha Rogers, and Sister Callista Roy, worked to demarcate nursing's empirical focus, establish the theoretical frameworks by which nurses could understand and influence patient health, and distinguish nursing science from the biomedical and behavioral sciences.

The theorists identified four concepts that would define nursing's focus: the whole person (not simply the locus of disease or disability); health (as opposed to disease and its treatment); the influence of the social and physical environment on an individual's health; and nursing—that is, what nurses do for and with patients to enable and support patients as agents in the pursuit of their own health goals. In this way, Ellis wrote, nursing "moved from doing *for* patients to working *with* patients, helping people to care for themselves and involving them in their care and decisions about their health." In addition to transforming patient care, this focus shaped the kind of knowledge produced by nurses and distinguished it from knowledge produced by physicians and biomedical researchers.

As academic nurses were constructing their science, academic physicians were establishing the discipline of clinical epidemiology and asserting the superiority of the randomized controlled trial for generating the most objective and reliable knowledge. They did so in the context of the quality assessment movement in health care, which aimed to systematically measure the outcomes of patient care. This would help determine which clinical interventions worked and which didn't, and hold physicians accountable for those outcomes (referred to as outcomes research). The primacy of the biomedical sciences, the growing importance of outcomes research, and the broader quality assessment movement in health care shaped the ways in which research methods and the evidence they generated were evaluated and accorded status.

VISIONS OF NURSING

ANNE WALLENTINE

During conflict or crisis—from wars and pandemics to individual health emergencies—nurses are often depicted in art as heroes and saviors. The necessity and respect for nurses' professional care emerges most conspicuously in these moments, exemplified in the early days of the COVID-19 pandemic by the signs thanking health care workers that sprouted on windows and lawns.

But nursing has been depicted in many ways as it evolved into a formalized profession over the nineteenth and twentieth centuries. From caps to scrubs, exemplars to essential (and exhausted) workers, the many changes in the profession over the past half-century have been reflected in nursing's representations in visual art and culture.

During World War II, government propaganda posters depicted nursing as a heroic choice in a bid to meet growing wartime needs. "Enlist in a proud profession!" blared advertisements for the US Cadet Nurse Corps, which featured and were aimed predominantly at women. The nurse on one 1943 poster (p. 77)—a perfectly coiffed, blonde, blue-eyed cadet in uniform haloed against a blue ground—appears at once angelic, inspirational, and professional, her idealized beauty playing no small part in the vision of success that the poster aimed to project.

The government-sponsored images of nurses in 1943 did not yet reflect the true diversity of the profession. After the war ended, a severe nursing shortage led the United States to recruit more nurses beyond its borders, informed by its colonial legacy. The United States had instated Americanized nursing training programs in the Philippines since colonizing the country in 1898, The randomized controlled trial had become the gold standard research method in clinical medicine by the 1970s. But nurse scientists preferred descriptive quantitative studies, observational studies, and qualitative research methods that relied on the invocation of theory rather than statistical analysis as a means of validation. As a result, the knowledge their research generated occupied a comparatively lower position in the so-called hierarchy of evidence. This led to nursing science and nurse scientists being undervalued within academia, even as nurse scientists contributed to clinical research what was missing from physicians' interventions-focused approach: evidence concerning the social and political context of patient care that could help explain why individuals made the choices they did about their own health and health care.

Nevertheless, nurse scientists, who were increasingly educated in nursing PhD programs, did secure their place within academia. They secured external research funding, engaged in research, published in peer-reviewed journals, and instituted nursing PhD programs—and did so during a time in which women scientists, in general, faired especially poorly. Historians of gender and science have described the postwar demise of predominantly female disciplines, such as home economics, and analyzed the efforts of women scientists to establish themselves within traditionally male disciplines previously closed off to them. The establishment of nursing science and the experiences of nurse scientists thus provides new insights into the experiences of women scientists and the intersections of gender, knowledge production, and discipline formation in the postwar decades.

Carolyn Moorhead Edmundson, 1943, 28 x 20 in. Courtesy UNT Libraries Government Documents Department.

and the combination of this educational system along with postwar legislation that encouraged migration enabled many more Filipina nurses to fill the country's needs for professional care. A 1976 graduation photograph of Rizalita Legaspi Aniel, Neruta Ladia, and Norma Lesada (p. 78) shows the three smiling new nurses in their starched, all-white uniforms and caps, representing at once the United States' colonial past and its diversifying future.

A drawing by Virginia Powell from the mid-1990s (p. 86) shows the further evolution of nursing as it relates to technology and training. The nurse sits at the bedside of a patient wearing an oxygen mask, monitoring the patient's condition after an operation. With the advent of ever-more advanced medical technology came changes in nurses' roles and education, including a shift from providing predominantly physical care to managing equipment and reading increasingly detailed monitors and scans. Keith Holmes's early 1990s portrait, *Nurse in Red* (p. 82), also reflects this increasing professionalization through the equipment in the background and the nurse's calm face and commanding pose, conveying her authority and expertise as she points beyond the frame with her gloved hand. Both works also show how nurses' uniforms continued to evolve over the decades. The nurse's red uniform includes a skirt and apron but no starched cap, which, although still strongly symbolic of the nursing profession, has gradually been eliminated for reasons of hygiene, practicality, and gender equality. Meanwhile, Powell's modern nurse wears scrubs and a hygienic bouffant cap, pushed back but still in place from the operating room.

(continued on p. 78)

Establishing educational pathways into nursing

By the 1960s, there existed multiple educational pathways into nursing. Hoping to resolve nursing shortages, nurse educators had introduced one-year licensed practical nursing (LPN) programs and two-year associate degree (AD) programs. In the resulting hierarchy, LPNs were tasked with the "traditional" bed and body work of nursing, while AD-educated nurses had greater clinical responsibilities than the LPN, but less than that of the BSN-educated nurses. The BSN-prepared nurse assumed the status of the "professional nurse" and the responsibilities of the expert and independent clinical practitioner. Professional nurses, typically after completing advanced graduate education, would go on to serve as clinical supervisors, educators, or administrators. Diploma-trained nurses (who had completed a hospital-based program) were expected to complete a BSN in order to be considered a professional nurse and to pursue career advancement.

This educational hierarchy, however, exacerbated existing hierarchies within the nursing workforce that stratified nurses by education level, family income, and class, and were further compounded by race. Shaped by the history of segregation and systemic racism, in the early 1970s the majority of Black nurses graduated from LPN, AD, and diploma programs. This subsequently limited their opportunities for career advancement, leadership, and faculty positions—all of which required at minimum a BSN degree.

Although some nurse leaders regarded the different educational pathways as hindering nursing's professionalization, the persistence of these pathways indicates their value in increasing access to nursing for underrepresented populations. It also highlights the varied interests—and political power—of nurses and other stakeholders in maintaining them. For example, during the 1960s and 1970s, the American Nurses Association and other nursing leaders pushed to close diploma programs and establish the BSN as the minimum credential for professional

Graduation photograph of Rizalita Legaspi Aniel, Neruta Ladia, and Norma Lesada, March 1976. Photo courtesy National Museum of American History.

Today, the practicality of scrubs and personal protective equipment (PPE) predominates among nursing uniforms. In 2020, Tim Okamura began painting highly realistic portraits of nurses during the early height of the COVID-19 pandemic, including face masks and shields that drive home the frontline nature of their roles. His painting of Jennie Vasquez (p. 85) shows her girding herself with layers of PPE in preparation for her work, while an image of Tamika Dennis (p. 75) reveals the more vulnerable aftermath of a shift as she removes her mask. These works are a far cry from the gloss of wartime propaganda posters, instead recognizing the precarity and humanness of the profession as overwork and understaffing continue to threaten public health.

The pandemic's stresses on the health care system and its workers over the past several years have fueled numerous nurses' strikes for better staffing and support to provide adequate care for patients. At one such strike at a Kaiser Permanente hospital in 2021, nurses held signs that read, "Heroes treated like zeroes" (p. 80). Photographs like these illustrate the tensions that underpin the profession as well as its depictions: nurses continue to be highly valorized but are often given inadequate support to do their difficult and demanding jobs. Still, representations of nurses continue to adapt just as the profession does—to new challenges, new mediums, and new visions of what a nurse can be.

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practice. But this was at a time when state and federal policymakers prioritized expanding access to and diversity within higher education. In this context, state legislators were persuaded by the arguments of diploma- and AD-educated nurses to keep and even expand the educational pathways into nursing because it fit their goals of expanding access to higher education while also addressing the health care needs of the state.

In Minnesota, for example, state legislators were under pressure from nurses to facilitate educational mobility for graduates of diploma and AD programs. These legislators, in turn, put pressure on the University of Minnesota, as the state's land grant institution, to resolve the problems of educational mobility by, for instance, creating accelerated registered nurse-BSN programs, awarding college credit for prior education and clinical experience, or enabling nurses to test out of classes that covered knowledge they already had competency in. In April 1971, state representative Verne Long wrote to the University of Minnesota's vice president for legislative affairs asking the university to help resolve difficulties nurses had faced in their efforts to attain advanced training. Long, who chaired the Minnesota House's higher education committee and was vice-chair of the appropriations committee, asked the university vice president "to direct your *immediate attention* to the problem…. If, in fact, the solution to these problems can be found … then I want to say in the most forceful manner I know how—let's have the answers forthcoming soon." The following year, Long asked the University of Minnesota dean of nursing to report on "the progress you have made in the areas of those [nurses] that are trying to upgrade their education."

The issue of educational mobility was, then, politically charged. As University of Minnesota nursing faculty member Mariah Snyder recalled, "Because of the two-year programs being in rural communities or outstate, legislators were not going to do away with the schools in their cities." The Minnesota Nurses Association (MNA) was also opposed to restricting access into professional practice by closing diploma or AD programs. After all, Snyder noted, the MNA's "largest membership was two- and three-year grads, so they weren't going to get behind this effort" to close two- and three-year programs. As a result, the state's registered nurses and the legislators who represented them expected the state's four-year colleges, and particularly the flagship University of Minnesota, to take the lead in facilitating the educational mobility of the state's nurses. The intersecting interests of nurses and state legislators thus helped to shore up nursing's educational system as one characterized by differential pathways into nursing.

Through the late twentieth and early twenty-first centuries, nurses and health care organizations continued to debate the merits of maintaining these differential pathways. In 2011, the Institute of Medicine (IOM, now the National Academy of Medicine) called for the proportion of nurses with bachelor's degrees to increase from 50% to 80% by 2020. It did so in response to more than a decade's worth of compelling evidence that hospitals with higher percentages of BSN-educated nurses had better patient outcomes. Nevertheless, the IOM recognized that the AD remained a critical entry point into nursing, particularly for people from rural areas, disadvantaged backgrounds, or underrepresented populations. Five years later, the IOM reaffirmed the importance of maintaining and strengthening the different educational pathways into nursing.

To be sure, these educational pathways have not resolved the problem of racial inequities in nursing. This is especially true within academic nursing, where 82% of full-time nursing faculty are white. Among registered nurses, 73.5% are white, and 84% of advanced practice nurses are white. Indeed, ongoing systemic racism has meant that Black, Indigenous, and other people of color continue to face barriers accessing higher education in nursing. This is reflected in the continuing marginalization of women of color in low paying, low status direct care occupations, such as nursing assistants and home health aides.

Much more work is needed to address these racial inequities and increase diversity within nursing, particularly at the highest educational levels. An essential component of this work is to provide support and resources for educational mobility within nursing—from the role of home health aide all the way to the advanced practice role—via articulated education pathways and the implementation of career ladders.

Nursing and its science sought to stand apart from the reductionist model of medicine that emphasized disease, diagnosis, and cure.

Building disciplines, confronting legacies

Nursing was not the only practice profession engaged in the work of building its discipline in the second half of the twentieth century. During these same decades, engineering, computing, clinical psychology, and pharmacy were embroiled in similar scientific and political debates as they undertook their own academic projects. For example, the emergence of computer science as an academic discipline in the period between 1955 and 1975 entailed a significant degree of boundary work with the academic disciplines upon which computer science drew for its people and its

Hospital staffers and union organizers waved signs and banners in protest over staffing shortages at Kaiser Permanente Hospital in Roseville on October 14, 2021. Photo by Fred Greaves for CalMatters, courtesy CalMatters.

content. It also led to significant tensions between academics and practitioners—that is, those working as computer programmers—particularly regarding the balance of theory and practice in computer science education.

Pharmacists were similarly engaged in a decades-long debate over educational reform and the academic requirements for entry into professional practice. By the 1960s, as physicians struggled to make sense of the ever-growing array of new drugs on the market, hospital pharmacists established themselves as drug information experts and played an increasingly critical role within the health care team. At the same time, community pharmacists began providing drug information and counseling to patients. In this context, the movement for academic reform—characterized by the push to expand clinical education and establish the PharmD (doctor of pharmacy) as the entry-level degree for the profession—gained greater traction. Nevertheless, it took until 1992 for pharmacists to finally resolve the debate, implementing plans to eliminate the bachelor's degree in pharmacy and establish the professional doctorate as the entry-level degree program.

Composed primarily of male scientists, engineers, and practitioners, the overwhelming majority of whom were white, these other science, technology, engineering, and mathematics (STEM) disciplines have, like nursing, had to confront a history of systemic racism and racial and social inequities in higher education. Understanding how nursing leaders chose to construct their discipline, determined which knowledge and thus which type of research had value, and selected who was invited to participate in that epistemological project provides important lessons for other STEM disciplines.

First, the multiple educational pathways into nursing that the profession was compelled to maintain have contributed to increasing numbers of racially and ethnically minoritized, rural, and low-income nursing students. This in turn has improved access to higher levels of education, particularly among historically marginalized and underrepresented populations. Recent government data indicate that nurses of color "are slightly more likely than their white counterparts to obtain a baccalaureate or higher degree during their careers."

Second, the way nurses defined their discipline—toward the agency of the patient—created an important model for focusing STEM disciplines on solving societal problems by understanding society itself. Nurses recognized that important factors in determining the effectiveness of any clinical intervention include how patients experience and respond to illness, how and why they make decisions about their health, and the social and physical environments in which they live. In STEM disciplines, rarely is it sufficient to create an intervention without also considering how people make decisions about whether and how to use the intervention. For example, engineers who build a new bridge also need to factor in how people will use the bridge; a bridge that is unused or overused is unlikely to solve the problem it was created to solve.

Finally, as STEM disciplines are called upon to support diversity, inclusion, and equity in higher education and careers, nursing's history makes clear that the choices made by health care professions and disciplines in the past—and, equally, in the present—have profound implications not only for who gets to work as a health care professional, but also for who has access to health care and how those with access experience the care they receive. So too, the professions and the disciplines that underpin them are critical to challenging discrimination and effecting change in the health care system.

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ANNIE Y. PATRICK

Finding the "I" in Interdisciplinarity

When I was assigned to a federally funded project to revolutionize engineering education at Virginia Tech, I thought being an effective scholar meant shunning my unconventional background. Instead, I had to embrace it.

In 2015, the National Science Foundation launched an effort to spur what the federal agency called an "engineering education revolution." The field had been teaching engineers the same way and drawing from the same populations for more than half a century, even as the world shifted. Virginia Tech's electrical and computer engineering department was one of over two dozen entities to receive $2 million for a five-year project to produce more culturally aware, diversely trained engineers. Named RED (for "revolutionizing engineering departments"), these grants required an interdisciplinary approach, stipulating that one of the co-principal investigators (PIs) have a social science background.

As a PhD candidate in science, technology, and society (STS), I became a research assistant on the project. Engineering professor Tom Martin, one of the forces behind the grant, had tapped my PhD advisor, historian of innovation Matthew Wisnioski, to be a co-PI. As social scientists, our expected role was to observe and advise. But the grant's mandate for radical change, combined with my own diverse background, ultimately led me to conclude that observation was not enough. After two years of traditional research, I took the unusual (for a social scientist) step of designing interventions to help the engineering community at Virginia Tech expand by recognizing diverse career paths, nontraditional students, and people who may not fit the description of a typical engineer.

Science has long aspired to crack the code of interdisciplinary research. When I joined the RED grant in 2016, it had been a little over a decade since the National Academies of Sciences, Engineering, and Medicine released their consensus report on facilitating interdisciplinary research, which had commenced with a call for urgency from a member of the White House Office of Science and Technology Policy: "There is this long-standing call for this type of research. The question we have to ask ourselves is, what is the problem? Why isn't this proceeding at a more rapid rate?"

It's now clear that interdisciplinarity is relatively easy to fund but hard to actualize. I was surprised to discover that becoming an effective interdisciplinary researcher also required that I embrace the value of what I call inner interdisciplinarity—my own unconventional background—and what it could bring to the team. My experience exposes conventions and infrastructure that so often keep interdisciplinary research from reaching its potential. It also suggests how to surmount such barriers.

"Eat this cracker and walk a few steps"

I didn't take a traditional path to a PhD; in fact, graduate school was never on my radar growing up in Mississippi in the 1990s. As a first-generation college student, I chose to study nursing because it offered a guaranteed job. After I began working at a hospital as a registered nurse, I learned about library and information science and started a master's degree program. Years later, chats with one of my patients, who happened to be the chair of the information technology department at the local university, inspired me to switch programs and earn a master's degree in network technology. A master's thesis about baby boomers and health care apps introduced me to qualitative research and landed me consulting work with a biostatistician who encouraged me to pursue a PhD. This led to my applying to graduate STS programs. I didn't know much about academic careers or the workings of higher education, but I knew I wanted to think more about how technologies shaped society and vice versa.

On the day that I learned I'd been awarded an assistantship that would enable me to join the STS program at Virginia

Keith Holmes, *Nurse in Red*, 1991–1993, oil on board, 25.2 x 18.9 in. © Keith Holmes. Photo credit: Science Museum / Science & Society Picture Library.

Tech, I was working as a nurse on the ambulatory surgery unit of a large teaching hospital in eastern North Carolina. I was partway through a typical day, clearing patients to go home after minor surgeries such as hernia repair or gall bladder removal. I had my charts open on the computer screen next to my email. When I read the message from the program's director announcing the position, I felt so overwhelmed that I went into the restroom and leaned against a stall to breathe through my eagerness and disbelief.

Minutes later, I had a new patient to assess. I explained the requirements he'd need to meet before he could leave: I'd make sure he could urinate, eat a cracker, sip ginger ale, and walk a few steps. Unable to keep my excitement to myself, I told him that I had just received funding to start my PhD. He looked at me blankly, waiting to be cleared.

Four months later, I gave away my scrubs, sold my stethoscope, and moved to Blacksburg, Virginia. I was eager to present myself as a scholar, which to me meant distancing myself from nursing. Although I couldn't see it then, it is now clear to me that there's something powerful about being a nurse. I've seen the worst in people and the best; I've cared for millionaires and homeless people alike; and I've seen how paying attention to people can improve health and save lives. I couldn't have realized then how important that experience would be in my new role—or how academia is biased toward individuals having only narrow expertise.

Dismantling rigidity

I quickly assumed my place in the weekly meetings about the RED grant. Our specific project was aimed at dismantling a rigid curriculum that had funneled students into either electrical or computer engineering, often leaving them stuck without the ability to explore all their options or the means to obtain the sort of interdisciplinary skills that today's employers need. The team worked with other faculty to cross-coordinate new curricula for undergraduate education that fostered both depth and professional breadth so that students were no longer tracked to a single narrow major. We hoped the revised curriculum would open possibilities for engineering majors and attract students from places beyond the wealthier, whiter regions of northern Virginia, where most enrollees hailed from.

Those first few weeks were a whirlwind of new language and concepts. Every time someone said a term like *circuits*, *photonics*, or *culture change*, I had to check in with myself that I was following the conversation. It wasn't just the words that were foreign: so were the customs, aspirations, and expectations of my new colleagues. I sat at a table with directors, department heads, and people from globally known institutions whose idea of the mundane felt exotic; people would talk about travelling internationally or attending elite universities as if it were as common as walking on two legs.

Although I couldn't see it at the time, feeling out of place was to my advantage. My role would be conducting qualitative interviews as part of a climate-and-culture study of the department, and I needed an outsider's perspective. When someone asked whether I would be intimidated by interviewing engineering faculty, I thought, "Why?" I had already learned to communicate with physicians, who were notorious for hanging up on nurses, not to mention family members who frequently gave me the third degree as soon as I entered their loved one's hospital room.

I soon saw similarities between the engineering program and my experiences as a nursing student. Engineering's concept of rigor mirrored nursing's expectations of perfection—for example, when instructors would interrogate me about the possible adverse effects of medication. Scholarly discussions about the toxicity of weed-out culture reminded me of *my* incoming class of 60 nursing students, which shrank to a graduating class of 30. And the engineering school's version of critical thinking, which was geared toward seeking out risks or weak points of system failure, felt more familiar than what STS considered critical thinking, which involved comparing different schools of thought through lenses such as cultural capital, power structures, and artifacts of technology.

Other skills from nursing quickly came into play when I started conducting interviews. I knew how to establish trust within minutes of entering a patient's room, and I had years of practice listening to patients tell meandering stories and redirecting them toward relevant details.

Over the next two years, I interviewed more than 50 faculty, alumni, undergraduates, and academic career advisors about the department's focus on research rigor, silos of research specialties, the way faculty staked out their own turf, and the lack of diversity in terms of race, gender, and socioeconomic status. I learned that faculty saw their role as preparing students for jobs in defense and technology or for advanced engineering degrees. Students seeking alternate careers lacked support; one double major told me he got better career advice from his creative writing instructor than from the program. I also heard students' accounts of how hard it was to be the only woman or person of color in an advanced seminar, to stick out among the "nerdy boys."

I reported these findings to the project team, and then I stepped away. The team's attention shifted toward meeting accelerated university deadlines, including analyses and updates for the curriculum committee, which was planning changes across an engineering department that included over 95 faculty and 1,100 students. Meanwhile, I took on other roles within the project team and became absorbed in the STS canon, exploring the works of scholars including Donna Haraway, Thomas Kuhn, and Bruno Latour. I was forced to challenge my own beliefs as I explored their theories and how they laid out frameworks of history, philosophy, and sociology to make inequities visible. But I didn't forget the data I had collected. I sometimes would review my files, fighting the urge to ask, "So now what?"

Engaged scholarship meets nursing interventions

In my second year in the doctoral program, I took a class called Engaged STS and found what I hadn't realized I was seeking: scholars actually making change. I recognized that my urge to intervene stemmed from my experiences as a nurse, where the question of "So now what?" is vitally important. Central to the profession is responding to patients' situations with carefully crafted "nursing interventions." A patient presenting with increased temperature after surgery? Assess other symptoms, administer Tylenol, reteach the patient to use a lung exercise device, wait an hour, and recheck vitals. When I saw something going wrong, my every professional instinct was to intervene. And having been trusted by my interviewees with their thoughts and experiences, I now felt compelled to respond; they were not simply informants or categories of data, but actual humans.

So I learned about critical participation and about making and doing, part of the low church of STS because it emphasizes social impact over theory and embraces action and participatory research. I passed my qualifying exam to continue the PhD program and—after some months of conversations—I embraced the role of intervening scholar.

My experience exposes conventions and infrastructure that so often keep interdisciplinary research from reaching its potential. It also suggests how to surmount such barriers.

At that point, I opened my files with the data from my interviews once more. With my advisor, I identified three problems my research had uncovered: people with marginalized identities felt unheard in the department, academic advisors had insights about students' lives that faculty members lacked, and students had difficulty finding practical information about career paths outside of defense and technology. These problems, we agreed, seemed ripe for intervention.

Eventually, I developed three interventions specific to these problems: a podcast, a seminar, and a white paper. I received enthusiastic support from the project team. After four years of Wednesday-morning grant meetings, they knew my work ethic and were willing to give me the freedom to do my projects and to lend help in ways that weren't spelled out in the grant. For example, Luke Lester, the head of the engineering department and PI of the grant, brought departmental support, prodding faculty to respond to my surveys and giving me slots to speak at faculty meetings. Lisa McNair, another co-PI and the engineering education expert on the grant, helped ensure that my work was aligned with national standards in engineering education, best practices, and goals.

For those who told me they felt invisible, I sought to provide a literal voice via a podcast called *Engineering Visibility*, where I interviewed students about their experiences. In an episode called "Seeing the Nontraditional Student," I talked with students who had arrived at Virginia Tech after following other paths from high school. Other episodes featured women in engineering, people who'd never expected to find themselves in graduate school, faculty describing what they value about teaching, students describing how they were coping with the pandemic, plus first-generation students and staff members devoted to their support. All along the way, I recruited alumni, students, and faculty to participate with the goal of helping the community of electrical and computer engineers recognize how much diversity they already had.

My next intervention tackled a different sort of visibility—that of engineers seeking nontraditional careers. In the research phase of the project, I had interviewed 18 undergraduates, including four pursuing nontraditional careers, who said they had few resources for exploring different options. I assumed there were many other students in their position, and thought they needed a forum to explore these opportunities. I assembled a panel of engineers from outside the mainstream, including a fashion entrepreneur, patent attorneys, and a financial professional, who together represented diverse ethnic backgrounds. In a 90-minute virtual conversation, they described how they used skills from electrical and computer engineering to get onto their career path, and then students could attend breakout sessions with the panelist of their choice. More than two dozen undergraduates and administrators attended.

My biggest challenge came when I tried to help the engineering faculty better understand their students. Engineering undergraduates at Virginia Tech are assigned professional academic advisors who are distinct from the engineering faculty teaching their classes. My research found that the advisors had a very good understanding of what students encountered in their day-to-day lives: financial struggles, family responsibilities, feelings of exclusion, and lack of belonging, plus other challenges that made it difficult for them to thrive—including being uncertain where their next meal was coming from. By contrast, most engineering faculty only discussed academic performance with those same students. They routinely attributed academic struggles to a lack of academic preparation, not a potential consequence of financial, social, or other struggles.

A conversation with a member of the engineering faculty showed me how to proceed. "We get numbers," they told me, speaking of their colleagues. So I collected data on over 1,600 student-advisor interactions to quantify the care work that advisors do. The result was a white paper intended to help faculty start to see their students as more than the problem sets they turned in (or didn't). Faculty were surprised, for instance, when I told them that academic advisors sometimes came up with ways to make sure students had something to eat. One of the key points of the white paper was to make the care work that the advisors do for students visible to faculty, who tended to value what they saw as academic rigor without recognizing the importance of supporting students in other ways.

Taken together, these three interventions enabled the engineering community to "see" itself as I had seen them—as distinct individuals, as seekers in search of satisfying careers, and as a community where multiple supports were required to graduate each student. One testament to the impact of these interventions is that the podcast is being continued under the director of communication and, as of 2021, had been downloaded hundreds of times. The white paper remains easy to find on Virginia Tech's website for others to build on. In their project report to the National Science Foundation, the Virginia Tech faculty on the grant wrote that there was now a better understanding of stakeholders across the department, including a new understanding of "concerns such as care work, sense of belonging, advising, and student success, particularly non-traditional forms of student success." Ultimately, members of my team produced 21 publications and presentations.

Along the way, I also developed a methodological and conceptual framework for other applied STS scholars to use by developing a concept I call "groundwork." Early on, I told my advisor I'd found nothing in the literature to tell me how to be an applied social scientist. He replied, "That's your dissertation." Groundwork is my attempt to provide language for my political, social, and emotional labor of intervening as a scholar. It gives social scientists an approach to negotiate interventions that protect vulnerable populations, to translate knowledge so different groups can respect it, and to measure success. I hope that other scholars can use the framework to structure interventions and build upon it to enhance engaged research more broadly.

Effective interdisciplinarity means more than combining individuals from different disciplines onto a team. It also means drawing out diverse expertise within individuals.

Interdisciplinarity across a team and within individuals

My experience speaks to that question posed about facilitating interdisciplinarity at the National Academies' convocation almost two decades ago: Why isn't this proceeding faster? I think one reason is that interdisciplinarity must go beyond bringing together a diverse team of specialists.

Yes, it made sense that the RED grants required PIs to represent distinct academic roles: a department head in engineering (or someone in a similar position to drive change), an expert in engineering education, and a social scientist to assess culture. But effective interdisciplinarity means more than combining individuals from different disciplines onto a team. It also means drawing out diverse expertise within individuals. It wasn't my nascent understanding of STS that led our team to pursue interventions but something harder to define: an environment where I could be more than my single specialty, where I could bring to bear my inner interdisciplinarity.

It took everything I brought into my PhD program to make my interventions happen: the registered nurse, the first-generation college student, the undergraduate trained in psychology and English, the master of information technology who'd assessed health tech, the eager intervening scholar, and the kid from Mississippi. Like me, most scholars have multiple levels of expertise and experience that would, if engaged, yield more creative, more influential work. But today, academia encourages them to leave these other identities and experiences at the door.

Social norms, academic infrastructure, and hiring practices all push academics to be just one highly specialized thing. We go to college and typically choose one major. From then on, it seems, peers and mentors identify us with a single, all-important specialty. I spent so much of my graduate career convinced that I had to select one area of expertise and stick to it steadfastly. That's why I thought my nursing background was a detriment to my success as an STS scholar. This mindset holds back interdisciplinary success.

Individuals should be empowered to offer myriad forms of expertise if they are able to engage their inner interdisciplinarity. My advisors gave me the respect and resources I needed to apply instincts from my nursing background to the project—including soft encouragement and hard cash for professional podcast editing. They even told me that the diversity of my experience had convinced them that I could get things done. In sad contrast, I had met others outside of the project who suggested that my abundance of ideas meant I should reconsider my decision to pursue a PhD.

Can this encouragement of inner interdisciplinarity be formalized by, say, taking the time for conversations within interdisciplinary teams to discover individuals' diverse experiences and how they might contribute? I saw something like this happening in Virginia Tech's new curricula. The write-up of the RED grant project outcomes describes one of the "most exciting and gratifying" changes in the department as hearing how students have started to introduce themselves. "They no longer just say, 'I'm an EE [electrical engineering] major,' they say for example 'I'm an EE majoring in Robotics & Autonomy with a secondary focus in Green Engineering.'" The four co-PIs on the grant were affiliated with Virginia Tech's Institute for Creativity, Arts, and Technology, which is devoted to interdisciplinary work at the intersection of science, engineering, art, and design. The revolutionized engineering curriculum actively encouraged students to include nonengineering courses in educational programs, including an official route to explain how they could bring engineering concepts into nondisciplinary courses and vice versa. Something similar, albeit more complicated and less formal, happened for me as a scholar.

Tim Okamura, *PPE*, 2021, oil, colored pencil, on wood panel, 48 x 60 in.

Virginia Powell, ca. 1995. A nurse monitoring a patient after an operation and taking notes. Wellcome Collection. Attribution 4.0 International (CC BY 4.0).

I'm convinced that there are ways to unleash inner interdisciplinarity through increased visibility and by emphasizing processes as much as (if not more than) outcomes—including how to build trust, infuse care, broaden what counts as success, and find language to communicate and meet project needs. Departments should be encouraged to take on such initiatives and incorporate them into decisionmaking even after the funding has gone away.

Ultimately, I'd like to see more formal mechanisms to break open boxes—both exterior and interior. Allowing multiple labels on job and grant applications would be a start. That could make interdisciplinarity a new norm, not only in curricula and research teams, but also in the way researchers and students identify themselves. Encouraging researchers to embrace their whole selves, moreoever, could provide crucial insights that make for more effective, relevant research. To capture those insights, academic norms and culture must first make inner interdisciplinarity visible, and then demonstrate that it is valued.

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E. WILLIAM COLGLAZIER

The Precarious Balance Between Research Openness and Security

Amid increasing competition and conflict with countries such as China, calls to restrict international scientific cooperation overlook benefits to the United States.

The United States is in the middle of a debate on the appropriate balance between openness and security for scientific research and development—a balance that has shifted significantly since the end of the Cold War. The COVID-19 pandemic, competition between the United States and China, the Russian invasion of Ukraine, increasing deglobalization, fraying supply chains, and current economic stresses have dramatically increased US political leaders' concerns with international scientific and technological collaboration.

This shift has bridged deep political divides to create a growing consensus among elected officials. The CHIPS and Science Act, approved by large majorities in the House and Senate in August 2022, along with new regulations from the Biden administration in October 2022, not only advance the US semiconductor industry but also limit China's ability to acquire certain advanced chips and manufacturing technologies. In January 2023, a bipartisan vote in the House of Representatives approved the creation of the Select Committee on the Strategic Competition Between the United States and the Chinese Communist Party to investigate issues such as the origin of SARS-CoV-2 and to recommend policy changes. In addition, a number of high-profile initiatives—with names like *Protecting US Technological Advantage* from the National Academies of Sciences, Engineering, and Medicine, or the "Task Force on Balancing Openness and Security Access Across the Department of Defense Academic Research Enterprise" of the Defense Science Board—have been examining how to protect US science, technology, and innovation given the challenge from China. All these and more could reset how openness and security are emphasized across America's science and technology enterprise.

Among the limits being considered are controls on whom US scientists can partner internationally with, what research can be openly published, and whether there should be additional restrictions on unclassified research—all of which would mark a distinct break with the policies of the last 40 years for fundamental basic research, regardless of whether that research is pure discovery or use-inspired. Before making such changes, a deep consideration of how that strategy of openness has benefited the country and propelled US preeminence in science, technology, and innovation is in order.

After World War II, American scientists were eager for increased international engagement to advance their country's science. The US government supported this partly as a way of understanding what scientists in other countries were doing and partly because US leaders saw science cooperation as a way to influence other governments and societies. Over the years, a doctrine of openness has evolved in the way the United States conducts basic research and engages in international research collaborations, including very large projects. Reducing this openness may have significant costs. The US scientific community will be less likely to learn what is being discovered by leading researchers in other countries, and restricting basic research relevant to security threats increases the possibility of the US government being surprised by developments with potential security risks. More broadly, limitations and restrictions aimed at foreign collaborations will slow the advance of science here.

From "ping-pong diplomacy" to "science diplomacy"

Relations between the United States and China improved from the era of "ping-pong diplomacy" in the early 1970s through Nixon's visit in 1972, but were not renormalized until the Carter presidency, with normal diplomatic relations resuming on January 1, 1979. Less than a month later, the Agreement Between the United States and China on Cooperation in Science and Technology was signed. That agreement, which formalized the exchange of scientists and students and scientific and technological collaboration, led to the creation of the Committee on Scholarly Communication with the People's Republic of China (CSCPRC), jointly founded by the American Council of Learned Societies, the Social Science Research Council, and the National Academy of Sciences (NAS), and administered by the NAS. The NAS opened an office in Beijing to facilitate scientific cooperation between the two countries. Scientific collaboration was seen as a low-risk way to strengthen their relationship. Thus, "science diplomacy" was an early and ongoing element of normalized relations.

My opinions on science diplomacy have been shaped by four decades of involvement in this scientific collaboration at many levels. In 1991, I took a sabbatical from the University of Tennessee to head the NAS international office in Washington, DC, overseeing and implementing the work of its committees such as the CSCPRC, the Committee on Japan, the Committee on International Security and Arms Control, the Committee on Human Rights, and the Board on Science and Technology for International Development. From 1994 to 2011, I was executive officer of the NAS and the National Research Council with responsibility for helping to oversee expert studies of the National Academies, which included those dealing with science and national security.

During these years, I made a number of trips to China to enhance cooperation and facilitate studies carried out jointly by the US National Academies and the Chinese Academies of Sciences and Engineering. The purpose of those studies was to advise our two governments on important issues requiring scientific expertise. Developing a strong relationship with members of the Chinese scientific community was seen as possibly helpful for increasing their ability to advise and influence the Chinese government as well as to advance science worldwide and develop solutions to some of the key challenges facing the world.

From 2011 to 2014, I served in the US government as science and technology adviser to the secretary of state; in that capacity, I engaged with US science and security agencies and with governmental and nongovernmental science officials and communities in other countries. The first international visit I made in this position was at the request of the Air Force Office of Scientific Research to join its team in meeting with South African scientists and institutions to explore potential collaborations in unclassified basic research with that office's funding. I became a fan of the approach taken by the basic research agencies in the Department of Defense (DOD) that recognized the importance of supporting open research domestically and internationally in areas that might become relevant for defense. Modest investments in international science have provided DOD with a window into the best science and scientists around the world.

Science diplomacy's special roles

Science diplomacy sometimes suffers from confusion about whether science is helping to advance diplomacy or diplomacy is helping to advance science. Science has proven at times to be a useful partner to help achieve diplomatic goals. One of the greatest successes was the Montreal Protocol on Substances that Deplete the Ozone Layer, finalized in 1987, which required the collaboration of scientists who raised concerns about the destruction of the ozone layer, corporations that developed refrigerants without ozone-destroying chlorofluorocarbons, and diplomats who pursued an international agreement. The same partnership helped advance the 2016 Kigali amendment to the protocol to reduce another class of harmful industrial gases, which the US Senate ratified in 2022. Similarly, the Intergovernmental Panel on Climate Change and its reports, including summaries negotiated between scientists and policymakers, have helped countries address the goals of the 2015 Paris climate agreement and contribute to international negotiations at the annual Conference of the Parties.

And, of course, diplomacy has also been useful for scientists—by, for example, reducing roadblocks that inhibit international scientific cooperation as has often occurred with visas and student exchanges. Scientists have returned the favor by demonstrating that personal relationships can facilitate progress on diplomatic issues. US and Soviet scientists who carried on informal, nongovernmental dialogues (often called Track II) in the 1980s contributed to advancing arms control of nuclear weapons in the 1990s. In the early 2000s, with the encouragement of both the US and Iranian governments, the two countries' science academies held joint workshops on issues including environmental protection, water conservation, earthquake protection, urban concerns, scientific ethics, and food safety. That collaboration continued for nearly 20 years, with several meetings held each year and frequent reports. Though the joint efforts didn't deal directly with nuclear issues, the good will generated between the countries helped enable governmental negotiations that led to the Iran nuclear agreement in 2015.

A precarious balance

In this era of competition and conflict, the balance between openness and security is precarious. In response to ethical lapses by scientists as well as legitimate security concerns such as patent infringement, inappropriate foreign talent programs, technology theft, and espionage, the United States and allied democracies are imposing new rules and restrictions on international scientific cooperation. So far, the scientific fields most affected are those in which China is investing heavily, such as artificial intelligence, synthetic biology, and quantum computing; all these emerging technologies have implications for national security and national defense.

Under the research security provisions of the 2022 CHIPS and Science Act and to respond to continuing government concerns, the National Science Foundation and other federal scientific organizations are charged with overseeing the improvement of security-related policies and training aimed at faculty, including disclosure of potential conflicts of interest or conflicts of commitment, and ensuring transparency of research funding sources such as those coming from foreign countries. The US scientific community has attempted to moderate some counterproductive elements of evolving federal policies and activities, including the FBI's arrest and Justice Department's prosecution of some Chinese-born scientists; those cases were ultimately dropped for lack of evidence. I believe the US government has constructively modified some of its dealings with individual scientists in response to dialogues with members of the scientific community.

Nevertheless, security concerns have left researchers unclear of what the rules are and facing increased roadblocks for international cooperation even in basic research. One effort to establish a new consensus regarding the rules is the National Academies study *Protecting US Technological Advantage*, published in September 2022. I am largely in agreement with the report's background chapters as well as a number of its findings, but the key recommendations leave many details up to the government through an ill-defined risk assessment process conducted by federal agencies.

For each defined threat, the report recommends using what it terms a "whole-of-government" interagency process for "developing an associated risk management strategy and

A doctrine of openness has evolved in the way the United States conducts basic research and engages in international research collaborations, including very large projects. Reducing this openness may have significant costs.

All these science diplomacy initiatives have convinced me that international scientific engagement is vital to America's national interest. To be at the forefront of rapidly advancing scientific and technological change in this globally interconnected world, US scientists have to engage with the best scientists wherever they reside. Moreover, building the science, technology, and innovation capacity of other countries helps to advance knowledge-based societies worldwide, which is also in America's national interest. Science collaboration should be seen as an essential diplomatic asset for the United States.

Politics remains, however, a more powerful force than science. Science diplomacy initiatives can be overwhelmed in the near term. Relations between the US government and the governments of Russia, Iran, and Cuba are more fraught today than a decade ago. With the Russian invasion of Ukraine, it's likely to be a long time before international scientific collaboration between Western countries and Russia returns. Relations between the governments of the United States and China have become much more difficult and are getting worse. Still, current tensions should not obscure the fact that one way to influence countries is through their scientific communities.

evaluation rubric for use by federal agencies in addressing the risk." My view of how to assess security-related risks of basic research is quite different. Assessing risks for each area of basic research potentially relevant for an emerging technology merits separate consideration. The only way to reach a workable, reliable, and timely risk assessment is through ongoing dialogue between top researchers in that field and representatives of the relevant government funding and security agencies.

In my view, the broad-strokes approach favored by this report will likely lead to overly conservative and prolonged risk assessments by agencies that will restrict basic research in important aspects. Such an approach will slow not only US scientific progress but the research needed to become aware of potential security risks. Especially concerning is the possibility of creating many more categories of "controlled but unclassified" research in areas with findings that were previously published in the open literature and are often conducted at universities where many of the leading researchers work.

research helped make the United States a magnet for talent from around the world.

Of course, there are other restriction mechanisms besides classification for some limited areas of fundamental research, including export controls and prohibitions on dual-use technologies under the International Traffic in Arms Regulations. These rules apply to research equipment as well as technical data that could have military or peaceful uses. Other examples include work categorized as Dual Use Research of Concern, such as research with dangerous pathogens, which requires review by the National Institutes of Health. It is clear, however, that potential risks of research related to a range of emerging technologies persist. For example, artificial intelligence developed to improve toxicity prediction for new drugs could be applied to developing new chemical warfare agents. Only with an ongoing dialogue between leading researchers and government agencies can some of these threats be anticipated and proactively addressed.

The January 2023 Meeting of Experts included representatives of research institutions—both universities

Security concerns have left researchers unclear of what the rules are and facing increased roadblocks for international cooperation even in basic research.

and national laboratories—as well as federal research funders and government agencies dealing with national security, intelligence, and law enforcement. Although the meeting generated no conclusions, recommendations, or written report, it prompted a constructive dialogue that considered multiple perspectives as well as potential paths forward. Participants agreed on the need for engagement with the scientific communities and governments of democratic allies who are also trying to balance openness and security in basic research relevant to emerging technologies. Yet, in my view, the dialogue did not produce a route forward that avoids problems with the approach recommended in the *Protecting US Technological Advantage* report.

A parallel effort to explore concerns regarding science and security occurred in January 2023 when the National Academies held a Meeting of Experts to discuss modifying National Security Decision Directive 189 (NSDD-189), which now operates as the "gold standard" for openness in basic research. This directive, issued in 1985, has remained in place over successive presidential administrations. It originated in the Reagan administration's response to a 1982 National Academies study known as the Corson report, named for the chair of its study panel. That report examined the need for controls on scientific information, technology, or knowhow that might reach the Soviet Union through open scientific communication. The key sentence in NSDD-189 states: "It is the policy of this administration that, to the maximum extent possible, the products of fundamental research remain unrestricted."

According to NSDD-189, when national security requires control over information generated from federally funded fundamental research, the appropriate mechanism is to classify that research. Thus, overall, the directive has a bias toward openness for government-funded work that has encouraged international cooperation for several generations. I believe this open environment in academic

A third effort could be very helpful in forging an understanding of the issues that underlie international engagement. In October 2020, the National Academies created a National Science, Technology, and Security Roundtable to provide a neutral venue where individuals from the national intelligence and law enforcement communities could meet with representatives from industry and the academic research community to discuss threats, opportunities, and potential risks. This consultation is intended to bring common understanding to the benefits and risks of openness and ideally will support informed decisionmaking.

The only way to reach a workable, reliable, and timely risk assessment is through ongoing dialogue between top researchers in that field and representatives of the relevant government funding and security agencies.

Looking to the future

Already, the heightened emphasis on security has meant that fewer Chinese students are coming to the United States for education. Further, I have heard from scientists in both countries who are now nervous about engaging in scientific cooperation with each other. Before the pandemic, China was the leading country for jointly authored publications with US scientists, but those numbers are now falling. Scientific cooperation between the United States and China in this new era is likely to be less robust than it has been in recent decades. And there is the possibility that the US-China science and technology agreement may not be continued.

As I have argued, the loss of basic research partnerships with China and other countries could have significant costs—to US universities that attract Chinese and other foreign students, to researchers doing collaborative work, and to the progress of global science. This trend comes at a time when research on shared concerns is sorely needed. International scientific engagement is essential for advancing science everywhere and solving the very global challenges that create geopolitical tensions—and so scientific leaders should work to maintain engagement with the world. Climate change, for example, has emerged as a national security threat for both the United States and other countries. And if the world is to make progress on technological and regulatory approaches to mitigating climate change, the United States and China need to cooperate in finding them.

In my view, one possible remedy is more in-person dialogue between the leaders of science in these two countries. Dialogues can be carried out by scientific academies such as the National Academies, professional societies such as the American Physical Society (APS), and umbrella scientific organizations like the American Association for the Advancement of Science. In the past, the National Academies and APS have done so and are now planning to do more. At in-person meetings, scientists can engage with each other to understand new rules for international scientific collaboration, including possible modifications resulting from national security concerns. In addition, these groups can discuss scientific integrity and the ethical standards required to advance science.

Joint meetings and dialogues will be helpful to prepare both American and Chinese scientists to discuss research collaboration with their own governments. Scientific leaders may need to explain to officials where certain rules and restrictions have gone too far and become counterproductive. Similarly, they may wish to explain to each other and their government leaders how past behaviors that were counter to the highest standards of science are detrimental to both scientific and diplomatic progress.

I believe no modifications are needed to the wording of NSDD-189. The US scientific community should push back against unclear and unnecessary changes to government risk assessment that would produce overly conservative restrictions. The US government needs to appropriate funding for the scientific research authorized in the CHIPS and Science Act as well as to encourage international scientific cooperation, including expanding cooperation with its democratic allies. Maintaining the openness that has served the United States well and made it a magnet for talent will require the US scientific community to take an active role in continuing to support open collaborations.

Further restrictions on research should be determined through ongoing dialogue and partnership among leading scientific experts, government funders, and security professionals. Such a process is far preferable to a generic requirement for agencies to develop a risk assessment approach likely to be poorly defined and laborious to implement. Failure to create clear and productive boundaries will ultimately discourage scientists from working in areas of basic research that are most critical for dealing with security concerns, including those associated with future pandemics and climate change.

With today's geopolitical turmoil, the United States is struggling to find and fix areas of weakness in the security requirements of its research system. But this is also a time to stop to fully consider the benefits that open collaboration in basic research have brought to the country's prosperity and security, as well as to spreading the values of openness, accountability, objectivity, fairness, and integrity that are fundamental to the scientific enterprise. There needs to be a deeper discussion of whether, by hurrying to address security concerns in a haphazard fashion, we may be shooting ourselves in the foot. I see no need to fundamentally change a strategy that has benefited our country so greatly.

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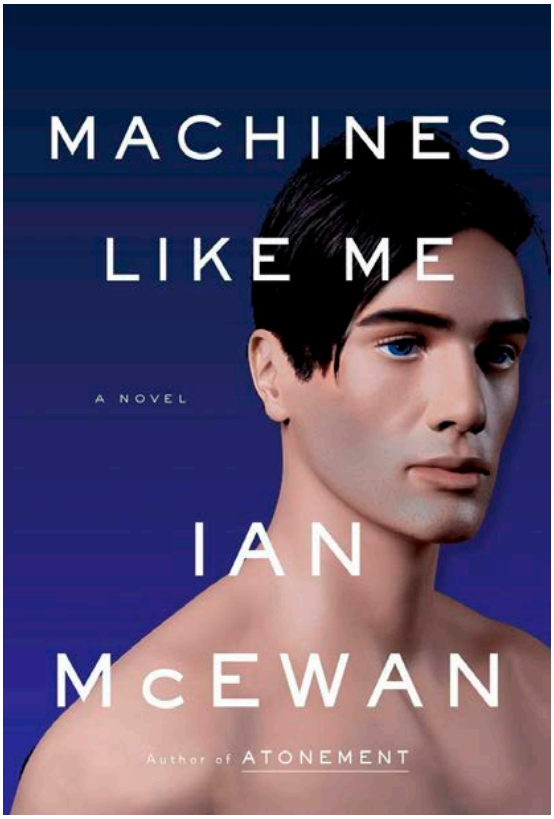
BOOKS

Not Your Father's Turing Test

DEBORAH POSKANZER

While I was immersed in three recent novels about artificial intelligence (AI), the media began breathlessly churning out stories about ChatGPT and GPT-4, the latest generation of large language model AI systems. Unlike their predecessors, these powerful language algorithms are capable of producing credibly human-like language in conversations, essays, and even poetry. Experts weighed in on the possible effects of the technology on everything from disinformation campaigns to academic essay-writing to white-collar employment. Interactions with these systems showed an unfortunate tendency to veer into unsavory territory, sparking viral memes about creepy AIs. "Why Do AI Chatbots Tell Lies and Act Weird? Look in the Mirror," read an acerbic headline in the *New York Times*.

One effect of the intense media coverage has been to shine a light on a heretofore obscure debate between two camps in the world of AI research: the true believers and the skeptics. The former declare that the threshold of true artificial intelligence is near at hand. If an AI can speak, learn, reason, plan, innovate, solve problems, and make decisions, it therefore possesses the "mind of its own" requisite for true intelligence. The skeptics assert that the semblance of an autonomous mind is just that: the result of our human tendency to anthropomorphize and create meaning where none exists.



Machines Like Me
by Ian McEwan. New York, NY: Nan A. Talese / Doubleday, 2019, 352 pp.

In the alternate universes of *Machines Like Me* by Ian McEwan, *Klara and the Sun* by Kazuo Ishiguro, and *The Employees* by Olga Ravn (translated by Martin Aitken), doubts about artificial intelligence have apparently been resolved. Not only do these humanoid synthetic beings equal or exceed natural humans in cognitive power, but they have the interiority and self-awareness of autonomous minds. Today's debate about intelligence has been superseded by the novels' uncertainty about artificial humans' *sentience* (experiencing sensations and feelings) or *sapience* (possessing wisdom, judgment, moral discernment, and other qualities unique to *Homo sapiens).* Nevertheless, the terms of the fictional debates are much the same as—and clearly informed by—our real-world one around AIs: Do human-like qualities indicate real humanity, or are they just sophisticated simulations that prompt the observer's projection of meaning?

Some fictional approaches to AI—the 2014 film *Ex Machina*, for instance—suggest that these questions are irrelevant, and the only test is the observers' perception. The Turing test of our parents' time has been surpassed: "The real test," the inventor character in *Ex Machina* says about his humanoid robot, "is to show you that she's a robot and then see if you still feel she has consciousness." In other words, if an entity makes us respond *as if* it were real—if our feelings overrule our cognition of artificiality—then the being is real. As in many films of this type, *Ex Machina* makes disentangling desire from reality especially challenging by embedding the AI in a very attractive body.

Machines Like Me, *Klara and the Sun*, and *The Employees* also play with perception, authenticity, and artificiality by placing natural and synthetic humans together in intimate settings, but they stand firmly on the other side of the debate. If an artificial human meets certain criteria, it can indeed be considered a real being, independent of observer projection. The meat of the books is in exploring just what the *sine qua non* of this selfhood might be. Is self-awareness a sufficient condition? Is it the experience of sensations and emotions? Do artificial humans have autonomous opinions, desires, and motivations? Are they bound by their initial programming, or are they capable of self-realization—or do they even have free will?

These three stories all belong to the venerable tradition of the creation myth. The trope of the invented being breaking loose from its bonds dates back at least to the medieval Jewish myth of the golem, if not to the Garden of Eden itself. In the Romantic period of the late eighteenth and early nineteenth centuries, Goethe's poem "The Sorcerer's Apprentice" and Mary Shelley's *Frankenstein* were both cautionary tales of misbegotten creations. In a late 1800s children's novel, Pinocchio yearns to be more than a puppet and achieves the transformation into a "real boy" when he develops a moral sense.

In modern popular culture, the myriad stories of robots run amok are evidence of our fascination with the consequences of humans' hubris in playing god. However, the three recent novels diverge from the mainstream of a genre dominated by doomsday scenarios. In much AI fiction, the specter of the so-called "singularity"—the point where artificial intelligence renders human civilization obsolete—looms as a dystopic backdrop. The dramatic tension often lies in whether the artificial being's opaque façade conceals a sinister intent. McEwan, Ishiguro, and Ravn invert this dynamic. Their artificial humans are unquestionably sympathetic; the dramatic tension derives instead from how much harm the humans are capable of inflicting upon their creations.

McEwan sets *Machines Like Me* in a parallel Britain closely resembling the real one. The critical difference is that in the alternate world, Alan Turing, the mathematician and father of computer science, chooses incarceration as the punishment for his homosexuality in the 1950s. Rather than being driven by the warping effects of chemical castration to what was officially declared a suicide, the novel's Turing spends a prison term in productive work on computing, greatly advancing the timeline for the development of artificial intelligence.

By the time the story begins in 1982, on the eve of the Falklands War between Great Britain and Argentina, embodied "artificial humans" have come to market packaged as "Adams" and "Eves." The human protagonist Charlie invites his friend Miranda to help customize his newly purchased "Adam" by alternating their responses to the preference questionnaire. As they collaborate on this project, their friendship turns to romance. Adam awakens as the synthesis of their choices: an apt if obvious metaphor for the genetic mingling of biological conception. Although Adam appears as an adult, he provokes his owner's bewilderment and frustration as he learns and grows in unexpected ways, much as a child might.

Outside Charlie's small apartment, the ripple effects of Turing's survival spread far beyond AI. Guided missile technology is also more advanced, but the Israelis achieve it before the British and sell it to Argentina. Britain loses the Falklands War, Margaret Thatcher resigns in disgrace, and the left-wing Labour stalwart Tony Benn succeeds her. Thus it is a Labour government that takes the blame for the crippling economic strife of the 1980s, precluding the emergence of Tony Blair and the "New Labour" faction. Not incidentally, the post-Falklands depression imperils Charlie's financial situation and sets up the terms of his final conflict with Adam.

As plot devices go, the far-reaching "butterfly effect" of Turing's choice is quite clever. However, as the travails of alternate-universe Britain accumulate, the story wanders far from questions of artificial life, becoming more of a lecture on late-twentieth-century British politics and society.

Of the three novels, *Machines Like Me* is the most explicit regarding the manufacture and performance of the humanoids. Early on, Charlie declares that "Adam is not a sex toy," and yet it turns out that many owners use their artificial humans for precisely that: McEwan describes the engineering of this function in lurid detail. In going where the other authors are too discreet to follow, McEwan propagates the pop culture trope of artificial beings (especially ones coded as female) as alluring, highly sexualized figures. These are legitimate authorial choices, but the absence of mystery and subtlety makes the book read more like a film treatment than an inquiry into the mysteries of the self.

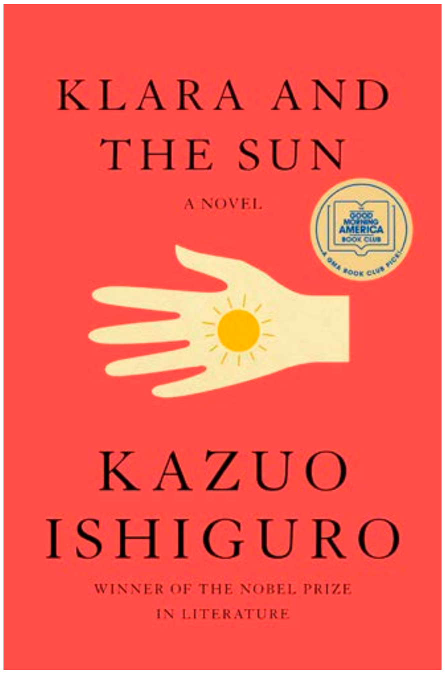
In contrast, Ishiguro's *Klara and the Sun* is suffused with mystery and wonder, a delicate tissue of complex emotions and allegories. The narrator of the story is Klara, a mechanical humanoid who serves as a combination of nanny and companion to Josie, an adolescent human. In this world, "artificial friends" are commonly purchased by well-to-do families to socialize and stimulate their home-schooled children. Most of these children undergo a risky process of genetic modification known as "lifting" in order to perpetuate their class advantage through increased intelligence. Josie's sister has died as a result of the procedure, and Josie herself is now chronically—perhaps fatally—ill. The plot revolves around Klara's increasingly desperate efforts to cure Josie, while also struggling to decode the motivations and expectations of the humans around her.

Ishiguro revisits perennial themes in his books, and *Klara* is enriched by echoes of his earlier novels. Klara is a being who finds fulfillment only in serving others: a mechanical version of Stevens the (human) butler in *The Remains of the Day* or Kathy the (clone) organ donor in *Never Let Me Go*. All three characters think of themselves as astute, observant caregivers to those around them, but the reader gradually perceives that they are highly unreliable narrators, naïve and baffled by human complexity. They are self-aware, but also deluded. Their interior monologues allow Ishiguro to explore the psychology of service and sacrifice. Klara is devoted, but does that qualify as love? Can she be a fully realized autonomous self at the same time as a self-sacrificing servant?

Pushing further into the philosophical issues of consciousness, Ishiguro probes the nature of the soul. In *Never Let Me Go,* the natural-born humans refuse to credit the clones with a soul. In *Klara*, a particularly odious character voices the belief that the soul is simply an artifact that can be replicated by coding in questionnaire data. Ishiguro stands instead on the side of a mysterious and ineffable soul, and as the story progresses, the aspect of religious parable becomes unmistakable. The solar-powered Klara worships the sun as the giver of all life, bargaining with it to save Josie just as biblical Old Testament figures did with their god. In her efforts to protect Josie, Klara becomes ever more self-abnegating and Christlike, culminating in the sacrifice of her vital fluid—albeit brain fluid rather than blood.

In *Klara*, unlike in *Machines*, the evolution of its alternate world is left to the imagination. The setting is somewhere that appears to be America, where society has fractured into clannish enclaves of the impoverished "post-employed" and a small upper class of the employed. The large number of British émigrés is unexplained, as is the derision directed at characters with British accents. The meaning of "lifting" becomes clear halfway through the book, and it takes even longer to deduce that Klara's repeated references to seeing in "boxes" are a visual processing glitch sparked by stress or confusion. These and other riddles have been the subject of numerous Reddit threads, but the opacity of Klara's world has a value beyond reader engagement. If the novel's theme is the riddle of existence—the ineffable nature of the self and the soul—then prodding readers into exercising their powers of imagination seems a better choice than McEwan's laborious world-building.

In Ravn's *The Employees,* the mystery around artificial life intensifies, from existential uncertainty to outright eeriness. In place of a conventional linear narrative, the story emerges through a *Rashomon*-like collage of "exit interviews" of a spaceship's crew. The interviews are not in chronological order, and the subjects have no names, only job titles. It emerges that the ship was originally on a lengthy voyage to collect exotic "objects" from distant worlds and that the crew comprised both natural-born humans and lab-grown humanoids.



Klara and the Sun
by Kazuo Ishiguro. New York, NY: Alfred A. Knopf, 2021, 320 pp.

It is difficult to distinguish which type of being is speaking in a given interview because the hopes and feelings they express are so similar: nostalgia for lost innocence, longing for friendship and love, pride in accomplishment versus boredom with routine, the urge toward self-determination and free will. The difference is that these sentiments are considered normal in the humans, whereas in humanoids their emergence is a threat to the orderly functioning of the ship. The formerly courteous relationship between the two classes has deteriorated into mutual suspicion, resentment, and possibly violence, and the mission has been forced to abort.

The radical departures of *The Employees* extend well beyond Ravn's unconventional style and structure. Most creation myths code their non-natural characters as "male" or "female," despite the superfluity of gender distinctions in manufactured beings. Ravn eschews this and other conventional binaries. The humanoids have no assigned gender, and the distinctions between natural and synthetic, and between sentient and non-sentient, are more of a spectrum than a binary. At one end of the spectrum are fully natural humans, then "augmented" humans who presumably possess physical or cognitive enhancements, then the lab-grown humanoids, and finally the objects in the cargo hold.

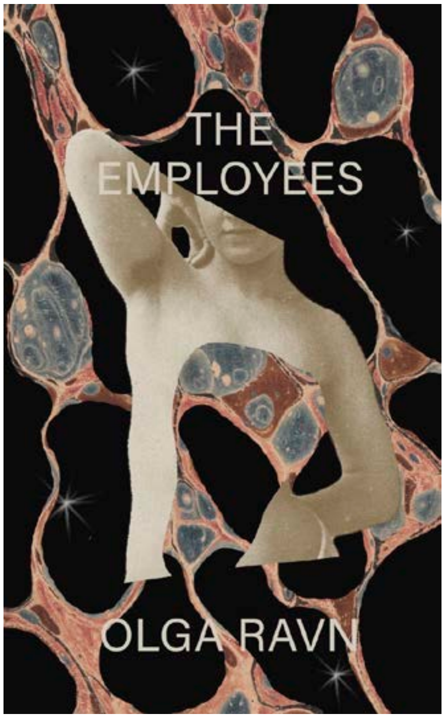
The presence of these objects adds a layer of black humor to the puzzle of semblance versus reality. The urge to anthropomorphize beings—especially ones that appear human—is understandable. But when the crew detect odors, secretions, and varying coloration in the objects, they attribute these to the "moods" of the objects and perceive them as fauna rather than flora. The crew commune with the objects on secretive visits to the hold and collect secretions for their soothing properties. Are the objects in fact sentient, or are the crew simply desperate for comforting companions?

The Employees is at heart a contemporary socioeconomic critique: the ship is peopled by anonymous cogs known only by their job descriptions and ruled over by sinister corporate owners. The workplace tension reflects the widespread emphasis of Ravn's generation (she is in her mid-30s) on reforming old ideas of work-life balance and labor-management relations in a society that is riven by inequality. In contrast, Ishiguro and McEwan have written what are essentially domestic dramas of mores and manners, with a veneer of social commentary.

Each of these novels—*Machines Like Me, Klara and the Sun,* and *The Employees*—takes the ostensible subject of artificial humans as a departure point for three disparate destinations: a lament for a declining Britain; a spiritual allegory of sacrifice; and a nightmare of alienated labor. They vary greatly in tone and style. The gap between their alternate worlds and the current state of artificial intelligence yawns so widely that only a feat of imagination can bridge it. None has any practical use as a road map to the future, nor do they add any clarity to our imprecise usage of "intelligence," "sentience," and "sapience." Nevertheless, the books are bound together by a common purpose, and their message speaks to our historical moment.

All the artificial beings in these stories are implanted with behavioral guidelines. Ravn's humanoid spaceship crew are meant to work productively and harmoniously alongside natural-born humans. Ishiguro's Klara is designed to nurture, while McEwan's Adams and Eves are customized to their owners' preferences. (Coincidentally, the last two authors use the device of a questionnaire to explore whether a personality is a reproducible artifact.) But over time, all these beings exhibit unanticipated qualities that exceed the boundaries of their initial programming. The "employees" evolve distinct personalities and abandon ship rather than submit to reprogramming. Klara uses dishonesty, subterfuge, and manipulation in her mission to save Josie. In Adam's world, some of the artificial humans, unhappy with their slavery, learn to deprogram themselves, committing a form of electronic suicide. Adam himself develops an opposite—but no less surprising—survival instinct, thwarting Charlie's efforts to shut him down. Like Klara, Adam is dishonest and disobedient in the service of higher moral principles.

Klara, Adam, and the anonymous spaceship crew follow what might be called an arc of emergence. "Emergence" refers to a complex system with properties that its individual components don't possess—that is,



The Employees
by Olga Ravn, trans. Martin Aitken. New York, NY: New Directions, 2022, 144 pp.

the whole turns out to be more than the sum of its parts. For philosophers of mind, the human mind is the quintessential emergent phenomenon, an entity that cannot be predicted from studying brain chemistry or physiology. The novels embed the mystery of emergence in plots about artificial humans, but they can also be read as an allegory for our real-world debate on nature versus nurture. Can we invent ourselves, or are we forever limited by the conditions of our creation? Recent advances in genetics and neurochemistry have pushed the pendulum far to the "nature" side, with science's ability to tinker with foundational elements of human physiology. But these authors push back against all forms of determinism, offering a forceful argument for agency and free will.

Speculative fiction, which is how I would loosely classify these novels, insists that there is and will always be a powerful interaction between technological and social change. This fiction doesn't pretend to predict the future any better than other methods. Indeed, it makes precisely the opposite point: that emergent qualities of complex socio-technological systems make such prediction impossible. These novels show what happens when we heedlessly allow technological advancement to outpace social and moral evolution. In *Machines Like Me*, London's Holy Trinity Church, the birthplace of abolition, stands at the geographical center of the action as a silent rebuke to the owners who treat their Adams and Eves as slaves. So too in *Klara and the Sun* and *The Employees*, artificial humans are regarded as chattel, undeserving of the rights and respect accorded to "real" humans.

Apart from McEwan's fictional version of Alan Turing, who embraces the humanity of artificial beings, the human characters in these novels are operating with an obsolete set of morals, unaware that future generations will look back at their moral failures just as we now look back at the evil of slavery. Speculative tales like these urge us to do better, by tempering the headlong drive for technological advancement with our sapient qualities of imagination, humility, and moral sensitivity.

Deborah Poskanzer *is an independent scholar who writes on energy use, modern Japan, and the nexus of environment, technology, and society.*

Archives

Installation view of Scott Hocking, *Arkansas Traveler*, 2020, found steel and fiberglass, in *New Earthworks*, April–September 2022, Arizona State University Art Museum. Photo by Tim Trumble.

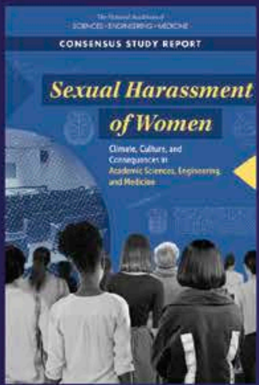
New Earthworks

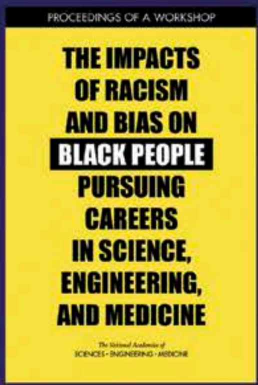
Can art help humanity rethink our understanding of the Earth and our interconnectedness with it? What role might artists play in envisioning new systems to address climate change and other environmental issues?

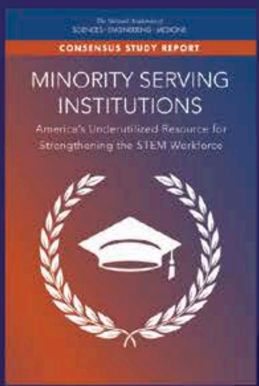
New Earthworks featured work by artists exploring these questions. Cocurated by artist Mark Dion and Arizona State University Art Museum curator emeritus Heather Sealy Lineberry, the exhibition was on view from April 9 through September 25, 2022, at the ASU Art Museum at Nelson Fine Arts Center in Tempe, Arizona.

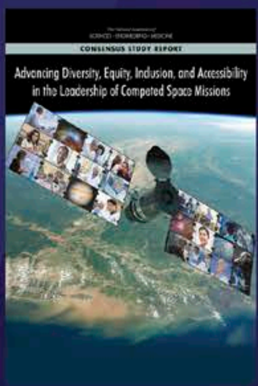
Inspired by—but not tethered to—the Earthworks art movement of the 1960s and 1970s, artists David Brooks, Carolina Caycedo, Desert ArtLab (April Bojorquez and Matt Garcia), Hope Ginsburg, Scott Hocking, Mary Mattingly, Sam Van Aken, and Steven Yazzie addressed issues of biodiversity and environmental equity, reasserted Indigenous ways of knowing, and imagined novel approaches to climate change.

For more information, visit **asuartmuseum.org**









Resources to Foster Diversity and Inclusion in STEMM

Removing barriers to entry and participation in science, technology, engineering, mathematics, and medicine (STEMM) fields, while also implementing practices that convey belonging, will allow higher education institutions and STEMM organizations to foster a culture of inclusion, thriving, and success.

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