

## CARE AND MAINTENANCE OF THE KNOWLEDGE MACHINE

*Research has given us hope that all  
Shall be well and all manner of thing shall be well  
Till the moment it's not. It's not.*

"POEM," MAUREEN MCLANE, *SAME LIFE*

NATURAL PHILOSOPHY BEGAN, as far as we know, when Thales of Miletus conjectured, in the sixth century BCE, that the elemental stuff of which the world was made was water. At that time, water was the lifeblood, if not of the universe, then certainly of the local economy: Miletus, controlling a harbor at the center of a vigorous trading network in the eastern Mediterranean, was in Thales's day said to be the wealthiest city in the world. Modern Miletus is a ruin, an empty place many miles from the sea. Centuries of deforestation and overgrazing allowed colossal quantities of silt to be washed into the Meander River and down into the bay that gave Miletus its access to the ocean. Year by year, the bay became shallower and then began to disappear. It is now the dry, dusty plain over which the remaining stones of Miletus preside.

The last of the sea withdrew from Miletus around 1500. Five hundred years later, it came to New York City. Hurricane Sandy brought a 14-foot storm surge that flooded low-lying areas throughout the five boroughs. In the lobbies of the Financial District, waves lapped around the



Figure 14.1. The remnants of the city of Miletus in the nineteenth century.

security cameras and the turnstiles, the filing cabinets and the flatscreen monitors. The power went out for a week.

The inundation, we are increasingly aware, was a visitation from the future. By the year 2050, according to one recent report, rising sea levels may have forced 300 million coast dwellers to abandon their homes.

The reasons for Miletus's demise could be counted out in terms of herds of goats and passels of timber; the underlying cause, however, was the Milesians' and their neighbors' unending desire for more. To satisfy their appetites, the wooded slopes of the interior were cleared and transformed into farmland; a naturally dry climate and relentless erosion did the rest. The richer Miletus grew, the faster it brought on its own destruction.

We moderns have our appetites, too. The consequences might seem quite as fearful. But even if the knowledge machine, by supercharging

industry, is in part to blame for the rapidity with which our proclivities and our proliferation have degraded our habitat, it offers us, at the same time, our best chance of salvation. Science will, if anything can, show us how to satisfy our wants without draining the earth of all that it needs to support life; it may also, if we treat it right, show us how to repair some of the damage that's already been done.

So how do we nurture the complex of individuals, institutions, and instrumentation that constitutes modern science so as to get from it the knowledge that will allow us to continue to live the good life? We must do two things. The first is to set the agenda, using grant money and government initiatives to steer a sufficient number of scientists toward questions that matter. The second is to secure the smooth operation of the knowledge machine itself, ensuring that it purrs—efficient, responsive, dynamic, and strong—as we career through the twenty-first century and beyond.

To address these matters in full would be a vast undertaking, another volume. With some regret, I put the question of agenda setting to one side. To make a start on the question of the maintenance of the knowledge machine's internal engineering will, however, be a satisfying way to conclude this book, taking a final, backward glance at my attempt to resolve the Great Method Debate. Let me begin by asking what my inspirations and adversaries, Karl Popper and Thomas Kuhn, might advise.

THAT ARCH-METHODIST, Karl Popper, predicated science and indeed civilization on a simple truism: a theory that makes mistaken predictions must itself be wrong. This, the principle of falsification, was the torch that Popper held high to light the path out of the darkness that had haunted his youth, away from social breakdown, mob violence, and mechanized slaughter.

A logical rule cannot be improved upon. But the scruples of the peo-

ple who employ it most certainly can. To that end, Popper believed that it was imperative to fan the critical spirit in science. Inside the white coats, behind the heavy spectacles, there must be installed a pitiless sensibility that would overlook no predictive defect—that would stand ready to call out falsehood, without regard to how hallowed, how plausible, or how beloved the faltering theory might be. A distinctly inhuman elevation of logic over loyalty, according to Popper, is what we should implant and cultivate in the human minds that make up the knowledge machine.

We've seen an insuperable technical obstacle to the Popperian plan. Logic alone cannot definitively falsify a theory; plausibility rankings—that is, subjective estimates of the likelihood of various auxiliary assumptions—will always play a role. Indeed, it is in virtue of these rankings that scientific opinion changes, ultimately flowing toward the truth in the course of Baconian convergence. A purely logical machine, then, will be a poor scientist.

Might we not strive, nevertheless, for scientific minds that are as unbiased, as unprejudiced, as unprovincial as possible? Certainly, a science of fierce, critical, selfless minds would be an extraordinary thing to behold—like the government of the just or the communion of the holy. But we'll see it only in our dreams. The knowledge machine is made of human beings, not an angelic host. We need a science that tolerates—or even better, harnesses—human frailty.

In any case, a science dominated by critical spirits might revoke the irrational elements of the iron rule, summoning philosophical and aesthetic reasoning back into scientific debate. The resulting enterprise would look less like modern science and more like the natural philosophy of old, like Descartes altercating across the centuries with Aristotle—and would perhaps be no more effective.

More of the critical spirit in our politics—yes. In our bureaucracies—yes. And in society at large—absolutely, yes. The world of human affairs could use far more than its meager allotment of Popperian rationality.

But to the exotic creature that is contemporary science, it would bring argumentation in suffocating excess.

THOMAS KUHN'S HANDBOOK for a healthy science makes a rather different set of recommendations. The great Kuhnian insight is that what distinguishes modern science from ancient and medieval science—that is, from “natural philosophy”—is not a superior logical tool kit or advanced technology, but a special form of social organization, the “paradigm.” This all-encompassing methodological framework provides the moral, intellectual, and emotional support that is necessary, as Kuhn wrote, for a scientist to “investigate some part of nature in a detail and depth that would otherwise be unimaginable.”

Kuhn's prescription for effective scientific inquiry is therefore to bolster the framework, to exalt the paradigm. All scientific research programs in a given domain must, at any one time, be corralled within a single, shared set of rules, shaped in accordance with a distinctive explanatory and methodological creed. Scientists working within such programs must be committed so deeply to the paradigm that they simply take its rightness for granted, finding alternative frameworks to be preposterous or even inconceivable.

The Kuhnian scientist is, as a consequence, not a free, critical spirit—and Kuhn thinks that this lack of freedom and criticism is essential to good science. A Kuhnian program of science education, aiming to optimize the power of the knowledge machine, will discourage autonomy, free thinking, and resistance to the status quo.

Kuhn is right about something fundamental to the operation of scientific inquiry—the importance, when going after empirical evidence, of passionate intensity—but his regime, like Popper's, asks for too much from its personnel. As 50 years of the sociology of science have shown, it is simply not realistic to suppose that scientists will follow the paradigm

as slavishly as Kuhn envisaged in *The Structure of Scientific Revolutions* or—more important still—that they will maintain complete faith in its validity under any circumstances short of its total collapse. The pungent mix of strength and weakness in the human will, sometimes assiduous and sometimes inattentive, and in the human spirit, alternately devoted and defiant, will see to that. A contingent of ideal Kuhnian scientists, working in strict adherence to protocol, is more redolent of a military parade than of a university department—and indeed, it is far easier to keep legs in lockstep than minds.

SO MUCH FOR THE old methodists, Popper and Kuhn. The new methodism proposed in *The Knowledge Machine* suggests three essential ingredients for a thriving science.

The first is fighting spirit. I don't mean Popper's critical spirit, scrutinizing the theoretical landscape from disinterested logical heights. What I have in mind is in far more plentiful supply: partial, self-interested ambition. Such ambition need not be low-minded; its interest in seeking out the truth and advancing human happiness may well be sincere. Nor need it be combative or mean—a great athlete can be full of grace. But it must be ready to play the game to win.

The fighting spirit must then be caged within the iron rule. The nature of the game is thus defined: from its players it will elicit the kind of evidence—arduous and expensive to produce—that hones the knowledge machine's sharp edge, and it will store that evidence securely for thinkers in the centuries ahead. The human race provides fighting spirit in abundance; the iron rule, by contrast, was hard to come by, because its demands are to all appearances contrary to reason. Indeed, as revealed by its war on theoretical beauty, they are in the fullest sense irrational. Nevertheless, the rule's dominion over all forms of inquiry into nature is now well established. "Only empirical testing counts" has come to feel normal, even rather boring.

Perhaps a little too boring. Thus, the third and last of the knowledge machine's needs, which might also be the most difficult, in our day, to satisfy. It is to leave science alone, that is, to resist the urge to tinker, to make science more current, more flexible, or, for that matter, more sensible.

The pressure to "improve" science could come from any direction—from funding bodies, technology companies, or political actors. It could even come from scientists themselves. One striking instance of this last possibility—of a mutiny against the iron rule from within the knowledge machine—may be seen in the arguments that have swirled around the status of string theory for the past 20 years or so.

String theory (more properly "superstring theory") has for decades been proffered as a promising "theory of everything," providing a unified framework to explain both gravitation, currently handled by Einstein's general theory of relativity, and the other fundamental forces, currently handled by the Standard Model of particle physics. String theory has many seductive features, but it is extraordinarily difficult to test in the way mandated by the iron rule. Certain experiments that would prove decisive would require, it is said, detectors the size of the planet Jupiter or particle accelerators as large as our galaxy.

In string theory's defense, some physicists have advanced what look like amendments to the iron rule. One suggested revision would allow string theory's unity, beauty, and coherence to count in its favor, not only in scientists' private thinking—that is already permitted—but in the course of official scientific argument. This amounts to a suspension of the iron rule's decree that all official debate go by way of empirical testing. The scientists who back the proposal are sometimes said to be advocating "post-empirical physics." Should such an endeavor be allowed?

It is an enticing prospect. I have said myself that aesthetic reasoning can yield deep insights into the principles of nature, and so that its exclusion from scientific argument violates a fundamental precept of rational

thinking. All string theory's champions are asking, then, is that the scientific method be given a logical upgrade.

And yet—the method has a function that transcends its lamentable logic. It is there to make profound, exacting experiment happen. Allow aesthetics into science, and the pressure to measure will subside. I can't say for sure that it will lead to disaster; the risk, however, is forbidding.

Do not, then, meddle with the iron rule. Do not tamper with the workings of the knowledge machine. Set its agenda, and then step back; let it run its course.

BUT I HAVE NEGLECTED to consult the radical subjectivists—those thinkers who hold that the machine, science, has no special method, no fixed operating procedure.

The sociologists Harry Collins and Trevor Pinch, paragons of radical subjectivism, compare science to a golem—an automaton made from inert matter and actuated by magical words written on paper and pushed into its mouth, supernally powerful but nearly impossible to restrain. "It will follow orders," they write, "do your work, and protect you from the ever threatening enemy. But it is clumsy and dangerous. Without control, a golem may destroy its masters with its flailing vigor."

When I suggest that science will better flourish if allowed to go its own way, then, Collins and Pinch might think that I have given a bad answer to the wrong question. What we should ask is: how can science be reined in?

The archetypical golem was brought into being in the late 1500s by the leading rabbi of Prague, Judah Loew ben Bezalel, to protect the city's Jewish population. According to one account, when it began to run amok, the rabbi had to take back the animating incantation—*emet*, the Hebrew word for truth—from the golem's mouth. His creation turned to dust.

In the legend, you might discern the radical subjectivist agenda: take away science's claim to absolute truth and it will be tamed. A more careful reading of Collins and Pinch's metaphor shows, however, that neutralization of the knowledge machine is very far from their aspirations. They take the golem to be a "bumbling giant," a "creature of our art and our craft," whom for all its faults "we should learn to love for what it is." The aim of their book is not to bring science to heel, but to understand how it works, to see how its knowledge is made.

That is my project, too. I do not, as you know, endorse the understanding of science proposed by subjectivists such as Collins and Pinch. They have overlooked the iron rule; consequently, they have missed the scientific method. Restore the method to its proper place at the heart of the machine, however, and the image of the golem retains its force.

The golem of legend was made of clay and brought to life by a magic word. The science golem's raw material is people, organized and empowered by the iron rule. (It is bronze, not iron, but otherwise the sculptor Eduardo Paolozzi's transmutation of Blake's Newton, shown in the frontispiece to this book, is an apt portrayal of a man made knowledge machine.)

The golem of legend had a mind of its own. Science is made up of many minds—those of a multitude of scientists, each interpreting the evidence in the light of their own culture and education, their own taste and inclination, and acting accordingly. Yet at the center of this multiplicity sits something further, the public arena in which scientific debates unfold. That we can understand as a theater of consciousness belonging to the golem itself. The golem's memory is the archive of observation and experiment; its trains of thought are the arguments published by disputing scientists. Such reasoning as goes on in the golem's head is therefore incomplete and conflicted. But at the same time, it operates at a remove from the human concerns of the people of which it is made.

Having waited so long and struggled so hard to create this thing, how can the human race best benefit from its existence? Point it in the right direction and let it go. Empirical science is a dull beast, but feeling no

pain and knowing no fear, it can do something that we with our refined minds and delicate sensibilities, so easily distracted, cannot. Snout to the ground, it is oblivious to the political and personal concerns of individual scientists, leaving their cultural baggage and petty self-interest behind.

This magnificent obtuseness may show us the way to sustainable happiness. It comes, though, with a cost and a compromise. The cost is irrationality: the creature abandons the baggage without regard for its value. The compromise is ambivalence: until Baconian convergence is attained, science makes no judgments about what the evidence shows, whatever individual scientists may believe.

Science's irrationality we'll tolerate, even welcome, if it lends the golem greater strength. For a society in search of answers, the ambivalence is rather more daunting.

The weather is getting wilder. Populations are on the move. Exotic diseases—Ebola, AIDS, SARS, MERS, Zika, COVID-19, which is rampaging as I write—are vaulting from animals to humans every generation. Technology is decreasing in size and growing in power like an ever more tightly sprung trap. We've pampered and praised the knowledge machine, given it the autonomy it has needed to grow. Now we desperately need its advice.



Figure 14.2. A cell heavily infected by SARS-CoV-2, the coronavirus that causes COVID-19

With enough evidence in—with Baconian convergence achieved or at least well on the way—there will exist a consensus among scientists that is functionally equivalent to science's speaking with a single voice. But at the moment when some critical concern assumes maximum urgency, the evidence is often patchy and provisional: different scientists, bringing different plausibility rankings to bear on the same question, will express diverse opinions. The voice of the golem in these cases sounds not like a harmonizing choir but like the babble before the music begins: the clamor of a thousand crosscutting conversations.

To make sense of the cacophony, we must find an interpreter. In the dire case of climate change, the foremost interpreter is the IPCC, the Intergovernmental Panel on Climate Change. Coordinated by the United Nations, the IPCC gathers scientists from around the world in working groups that contribute to assessment reports issued every few years. The aim of the reports is to summarize the state of scientific knowledge concerning the climate; among other things, they assign confidence levels to hypotheses, perhaps attaching "medium confidence" to one and "very high confidence" to another, and they assign likelihoods to particular events—such as a 3-degree increase in average global temperature by 2050 or a 5-inch increase in sea level by 2100—using expressions such as "more likely than not," "likely," "very likely," and so on. (In the same way, the UK, US, and other governments have convened committees of experts during the COVID-19 crisis to extract predictions, as best they can, from a bewildering array of conflicting epidemiological models.)

Such a panel, for all its expertise and hard work, cannot determine what science says. Science holds no determinate views. The IPCC's numbers are created, as all such numbers must be, by infusing the scientific record with a set of plausibility rankings. Although the IPCC aims to use a range of rankings that reflect, in some sense, the center of mass of scientific opinion, they are subjective all the same: they are not derived from the objective evidence, but are rather what must be added to the evidence to induce it to begin to talk. It follows, says Stephen Schneider,



Figure 14.3. Hurricane Sandy floods the Brooklyn-Battery Tunnel in New York City, October 29, 2012.

a lead author of several of the IPCC reports, that “if we care about the future, we have to learn to engage with subjective analyses.”

We do indeed. Interpretation requires a worldview. Kuhn taught that science is blind to any worldview other than the prevailing paradigm. He overstated its intelligence and sophistication: it is blind to worldviews altogether. The unstinting focus that results is what makes science so inexorable a stalker of knowledge. To fathom all the knowledge it finds, however, we must bring our subjectivity to the task, looking into the monster’s mind with human eyes. In this one crucial respect, the radical subjectivists are right.

*THE KNOWLEDGE MACHINE* opened in the darkness of prehistory. Civilization’s sun rose, bringing literature and law, temple domes and proscenium arches, and the more abstract pleasures of mathematics and

philosophy. Science's sun, meanwhile, remained deep below the horizon. To one surveying the cultures of the ancient world, there was no glimmer to suggest that anything like modern science would arise. So it continued for centuries, millennia. Empires came and went; each left its enduring aesthetic and intellectual gifts to humankind, but there was no science.

At a stroke, the Scientific Revolution changed everything. Science's sun seemed to have appeared, not on the horizon, but at its zenith, as the fierce genius of Newton and his lieutenants glistered in the heavens. It burned far hotter than had even the sun of civilization. Our sultry, teeming, denatured planet is its consequence—as are our increasingly long, comfortable, amusing lives.

Galileo yearned to know the nature of light. "I had always felt so unable to understand what light is," he wrote to a friend, "that I would gladly have spent all my life in jail, fed with bread and water, if only I was assured that I would eventually attain that longed-for understanding." Less than four hundred years later, thanks to Isaac Newton, James Clerk Maxwell, and Albert Einstein—along with many others—we have that knowledge. The light of science calls out for the same understanding. In *The Knowledge Machine*, I have given you the truth as I see it.

Science is not light; it is not promulgated by a star. Nor is it a golem, a glass slipper, a neurasthenic bird, or a coral reef. It is not, indeed, a machine. It is a social institution. It could not be brought into existence by a celestial body or by a magical incantation. Inquirers had to give the rule that constitutes the scientific institution to themselves. But the iron rule is a peculiar mix of power and perversity. Logically, it is beyond the pale. It would take an exceedingly long time for social, political, and moral conditions to twine themselves into a perspective from which the rule would seem to be an acceptable idea, fit to enter the halls of inquiry. Now we know. And because of the iron rule, we can go on knowing, more and more. Let us hope that knowledge saves us.

## ACKNOWLEDGMENTS

I couldn't possibly list all the writers, readers, teachers, and students who played a role in the genesis of *The Knowledge Machine*, even if I could tease apart the tangled lines of influence and figure out who had prompted, or gently undermined, which ideas. Two of the most important influences, however, have been my former colleague Peter Godfrey-Smith, who helped me to appreciate better the history and sociology of science and with whom I first taught Kuhn, Popper, and many of the other figures in this book, and Philip Kitcher, whose work inspired my first investigations of the social structure of science and who has been a reliable source of insight and support ever since.

Many friends read and commented on various parts of the manuscript: Joy Connolly, Erik Curiel, Rebecca Goldstein, Leanna McLennan, Ashlé Miller, Marco Nathan, Katie Tabb, and J. D. Trout. I thank them, along with Trevor Teitel, for his help in searching the physics literature for nonexistent references to beauty, and Maya Jasonoff, for a bracing excursion through the space of all conceivable titles. Thanks also to the Kavli Foundation and to Steve Hall and Gary Marcus for an inspiring but only too brief education in the art of science writing.

This book would have been quite different, and far inferior, without the exacting attention of two editors: Bob Weil, my editor at Liveright, and Jessica Loudis. Bob's finely judged blend of patience and exasperation, exerted over five long years of writing and revision, was more

than any writer could have reasonably expected. I am deeply grateful. It is equally difficult to imagine making it through that long period of gestation—roughly three elephants' worth—without the support and advice (not always concerning writing) of my agent, Chris Calhoun.

As for the business end of the book, I have much appreciated the care and attention of all the people at Liveright—in particular, Gabe Kachuck, Phil Marino, and Marie Pantojan, to name those I worked with directly—my scrupulous copyeditor, Janet Greenblatt, and my indefatigable, unsurpassable image researcher, Trish Marx.

Finally, my thanks to the Magnusons for the use of the Moog, where the book began and prospered.