The Restless CLOCK

A History of the Centuries-Long Argument over What Makes Living Things Tick

Jessica Riskin

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INTRODUCTION

Huxley's Joke, or the Problem of Agency in Nature and Science

On a Sunday evening in November 1868, the English naturalist Thomas Henry Huxley, professor of natural history at the Royal School of Mines and of anatomy and physiology at the Royal College of Surgeons in London, friend and defender of Charles Darwin, made a joke about which people continue to chuckle almost a century and a half later, and whose humor perfectly captures what this book is about.

Huxley had been invited to Edinburgh by a renegade clergyman, the Reverend James Cranbrook, to inaugurate a new series of "lectures on non-theological topics." Huxley chose as his non-theological topic, *protoplasm* or, as he defined it for the uninitiated, "the physical basis of life." His main point was simple: we ought, he said, to be able to understand the properties of protoplasm, including its quite extraordinary property of being alive, simply in terms of its component parts, without invoking any special *something*, any force or power called "vitality."[1]

After all, Huxley pointed out—here's the joke—water has extraordinary properties too, but we know that it is made of hydrogen and oxygen combined in certain proportions within a range of temperatures, and we do not "assume that something called 'aquosity' entered into and took possession of the oxide of hydrogen . . . then guided the aqueous particles to their places." To be sure, Huxley continued, we do not presently understand just how water's properties

follow from its composition any more than we understand how protoplasm can be alive, yet "we live in the hope and in the faith that . . . we shall by-and-by be able to see our way as clearly from the constituents of water to the properties of water, as we are now able to deduce the operations of a watch from the form of its parts and the manner in which they are put together."[2]

Huxley's lecture was a huge hit. When it appeared in print as the lead article in the *Fortnightly Review* the following February, several editions of the issue sold out immediately and John Morley, the review's editor, reckoned no article for a generation had "excited so profound a sensation."[3] The quip about aquosity continues almost a century and a half later to reappear regularly in biology textbooks and works of popular science.[4] A successful joke condenses layers of implicit argument and assumption into a very few words. In violation of the principle that one should never explain a joke (and in confirmation of the general feeling that the simpler the joke, the longer the explanation), this book offers an extended explanation of Huxley's joke. In particular, *The Restless Clock* addresses three of its aspects.

First, the joke assumes a founding principle of modern science, namely, that a scientific explanation must not attribute will or agency to natural phenomena: no active powers such as "aquosity" that "take possession" of things and "guide" them along their way. This rule also disallows, for example, explaining the falling weight driving a clock by saying that the weight wants to move closer to the center of the earth, or explaining the expansion of steam in a steam engine by saying that the steam intends to move upward toward the sky.

Second, Huxley's joke plays upon the uncertainties and hesitations involved in extending this principle banning agency to the explanation of living phenomena: in affirming that "vitality" is no more useful or scientific a concept than "aquosity."

Finally, in place of explanations invoking mysterious powers such as "aquosity," Huxley recommended mechanist scientific explanations that took as their model of nature the workings of an artificial machine such as a watch.

The Restless Clock examines the origins and history of the principle banning agency from science and this principle's accompanying clockwork model of nature, in particular as these apply to the science of living things. The *Restless Clock* also tells the story of a tradition of dissenters who would have rejected Huxley's punchline since they embraced the opposite principle: that agency is an essential and ineradicable part of nature.

You have probably already noticed that "agency" is a key word in this book.

Therefore let me begin by saying what I mean by it. I mean something like consciousness but more basic, more rudimentary, a primitive, prerequisite quality. A thing cannot be conscious without having agency, but it can have agency without being conscious. For example, one might consider a plant's phototropic capacity to seek sunlight to be a kind of agency, without meaning to ascribe consciousness to the plant. One might see certain electrical phenomena as exhibiting agency, such as the movement of electrons to maintain a conservation of charge.

By "agency," then, I mean simply an intrinsic capacity to act in the world, to do things in a way that is neither predetermined nor random. Its opposite is passivity. The reader will encounter in this book many scientific ascriptions to natural things—and many denials—of various forms of agency: living forces, sensitive capacities, vital fluids, and self-organizing tendencies. A common feature unites these ascriptions and denials: in each case, the ostensible force or tendency or capacity would originate *within* the natural form in question. A thing with agency is a thing whose activity originates inside itself rather than outside. A billiard ball that starts to roll when another billiard ball smacks into it looks passive: its movement appears to originate outside itself. What about a compass needle swinging around to point north? An asparagus fern sending a shoot across the room overnight? One might consider that many things in nature, if not most, exhibit agency: an activity that appears to originate within themselves.

However, the scientific principle banning ascriptions of agency to natural things supposes a material world that is essentially passive. This principle came into dominion around the middle of the seventeenth century, during the period that historians generally identify as the origin moment of modern science, or the New Science as its inventors called it. It is the informing axiom of a mechanistic approach to science. Mechanism, the core paradigm of modern science from the mid-seventeenth century onward, describes the world as a machine—a great clock, in seventeenth- and eighteenth-century imagery —whose parts are made of inert matter, moving only when set in motion by some external force, such as a clockmaker winding the spring. According to this originally seventeenth-century model, a mechanism is something lacking agency, produced and moved by outside forces; and nature, as a great mechanism, is similarly passive. Assuming that living beings are part of nature, according to this model, they too must be rationally explicable without appeal to intentions or desires, agency or will.

This ideal of explanation is standard in the natural sciences, and even the

human and social sciences frequently strive for natural-scientific explanations in which agency is absent. The ban on agency seems as close to the heart of what science *is* as any scientific rule or principle. To violate it seems tantamount to lapsing out of science into mysticism.

Yet historical scrutiny reveals that this model of science itself had a theological origin. A material world lacking agency assumed, indeed required, a supernatural god. The seventeenth-century banishment of agency, perception, consciousness, and will from nature and from natural science gave a monopoly on all of these attributes to an external god. The classical mechanist approach to science, with its attendant mechanical model of nature and of living creatures, relied crucially as it was developing from around the mid-seventeenth century upon an accompanying theology, namely the argument from design. The authors of the argument from design sought proof of the existence of God in the evidence of mechanical design in nature, God's artifact. For example, physiologists who scrutinized the structure of the eye described a close resemblance to a lens instrument such as a microscope or a telescope. One cannot have a lens instrument without an instrument maker, they argued—a microscope does not put itself together from parts—so likewise, one cannot have an eye without a divine Optician.

A purely passive artifact world devoid of agency would not have been a plausible account of living nature on its own and it won no converts on its own. This mode of science, call it theological mechanism, relied upon a divine Designer to whom it outsourced perception, will, and purposeful action. In other words, the principle banning agency from nature and natural science was not only an informing principle of modern science, but was simultaneously an informing principle of modern theology.

The Protestant Reformation, which starkly distinguished God from His works, was the theological sea change that preceded the modern model of nature as passive machinery. The Reformation transformed the world not just for Protestants but for everyone: this story features a mix of Catholics, Protestants, Deists, and others: Jews, Unitarians, Muslims, Latitudinarians. Despite their cultural and theological differences, from the seventeenth century onward these actors oriented their work in relation to a prevailing model of nature. This model represented a nature composed of intrinsically inert mechanisms whose passivity indicated a supernatural source of action.

In short, a contradiction sits at the origin of modern science. The central principle responsible for defining scientific explanations as distinct from reli-

gious and mystical ones was the prohibition on appeals to agency and will. This principle itself relied for its establishment upon a theological notion, the divine Engineer, and a theological program, the argument from design. To put it another way, when the inventors of modern science banished mysterious agencies from nature to the province of a transcendent God, they predicated their rigorously naturalist approach on a supernatural power. They bequeathed to their heirs a dilemma that remains active over three centuries later.

Current scientific accounts of living phenomena are permeated by officially disallowed appeals to agency. I talked about this with a friend who is a biologist, and she agreed that it is absolutely against the rules in her field to attribute agency to a natural entity such as, say, a cell or a molecule, but she also agreed that biologists do it constantly, just as a manner of speaking: they speak and write *as if* natural entities expressed all sorts of purposes and intentions, but they don't mean it literally. "Sure, we do it all the time, when we're teaching, in lectures, even in published articles. But it's just a sort of placeholder for things we don't know yet. The more we get to know, the less the phenomena will seem purposeful. In the meantime we talk as if natural entities had intentions and desires just to make it easier to talk about them." (This sounds to me like Huxley's projection of a future complete understanding of water in terms of its component parts.)

Certain verbs, my friend further specified, are worse than others: those that seem "anthropomorphizing," such as "want," are only permissible in casual settings. Biologists can say, and allow their doctoral students to say, that "cells want to move toward the wound" in conversation but never in print. In contrast, other active verbs do not seem anthropomorphizing. The example my friend chose was "regulate": proteins "regulate" cell divisions. She said she does not see this sort of verb as ascribing agency in any bad, anthropomorphic way—it does not attribute human desires to a cell, for example —but rather as shorthand for a complex process that would be cumbersome to spell out on each occasion and that anyway often contains elements beyond the current reach of biologists' understanding.[5] This sort of active verb is permissible and even widespread in journal articles and textbooks. Proteins "control" chemical reactions; muscle cells "harvest" energy; genes "dictate" the production of enzymes.[6]

Still, while "regulate," "control," "harvest," and "dictate" do not ascribe human emotions to genes or proteins, they do imply purposeful action. Furthermore, I asked my friend, isn't it really an article of faith, this conviction that if you knew everything about the systems you study, the things that look purposeful would

turn out to be entirely rote? There was a brief silence while she generously pondered the question. Then she laughed and said, "Yes, OK, you're right: it's a matter of faith. And, as with any matter of faith, I am absolutely unwilling to consider the possibility that it could be wrong. I *know* that if I knew everything about the processes I study, I would have no reason to appeal to agencies of any kind, even as a manner of speaking, let alone as a means of explanation."

I think that biologists' figures of speech reflect a deeply hidden yet abiding quandary created by the seventeenth-century banishment of agency from nature: do the order and action in the natural world originate inside or outside? Either answer raises big problems. Saying "inside" violates the ban on ascriptions of agency to natural phenomena such as cells or molecules, and so risks sounding mystical and magical. Saying "outside" assumes a supernatural source of nature's order, and so violates another scientific principle, the principle of naturalism.

Many before me have identified this quandary. Beginning in the seventeenth century, some sought to avoid it by rejecting the argument from design and the passive-mechanist model of natural science that went with it. The title of this book comes from a work that epitomizes the competing, active-mechanist view of natural machinery, and even of artificial machinery such as clocks. The German philosopher, mathematician, and inventor Gottfried Wilhelm Leibniz wrote the clockwork passage that provided this book's title as he was struggling to find a different model for nature and science from the passive machinery of his contemporaries. He described clockwork and, by analogy, human beings in this way: "In German," he wrote (he was writing in French), "the word for the balance of a clock is *Unruhe*—which also means disquiet; and one can take that for a model of how it is in our bodies, which can never be perfectly at their ease."[7] As Leibniz saw it, the balance of a clock was in a constant state of agitated motion, and so too were human bodies.

To be clocklike, to Leibniz, was to be responsive, agitated, and restless. How different this is from what people generally understand by the clockwork metaphor! The clockwork universe with its clockwork creatures has familiarly signified regularity and constraint, not agitation and responsiveness. In Leibniz's alternative notion of machinery and mechanist science, however, machinelike meant forceful, restless, purposeful, sentient, perceptive. Mechanical meant lifelike, and vice versa: living beings were the most mechanical things in the universe.

Since the classical mechanists were by and large the victors who wrote the histories, their opponents have had a bad reputation in historical and philosophical writing as mystics and even superstitious reactionaries. I should say

that by "classical mechanists," I mean Cartesians, Newtonians, Robert Boyle and his followers: the groups that played the dominant role during the seventeenth century to define modern scientific principles and practices. Although they disagreed with one another on many matters, including the source of action in nature's machinery, they agreed that the material world needed to be set in motion by an external power. Their critics argued that the machinery was self-moving.

Despite their reputation, critics of classical mechanism and the argument from design included a distinct group who objected not out of a commitment to traditional, religious accounts of nature, but rather out of a rigorous naturalism: a determination to establish science as fully autonomous. As Leibniz pointed out, if one wanted to disallow appeals to a supernatural god, then passive clockwork would not work as a model of living nature. One needed a different model: active, restless clockwork. Such a model would naturalize the very phenomena that the argument from design outsourced to a divine creator: perception, will, purpose, agency. All of these had to be integral to the natural world and its creatures.

From this impulse to naturalize rather than to outsource agency, there emerged a different mechanist science: not classical mechanism—brute, passive—but active mechanism. This alternative science was still mechanist, in that it offered rational, systematic accounts of natural phenomena in terms of component parts and their functions. It invoked no magical or miraculous properties, only natural ones. However, active mechanists such as Leibniz described the machinery of nature as containing its own sources of action inside itself: as self-constituting and self-transforming machinery.

Modern scientific accounts of life have been shaped by a struggle between these two competing mechanisms, two scientific principles. One, passive mechanism, the overtly victorious and therefore more visible, evacuates agency from nature (initially to the province of a supernatural god). It informs, for example, the physiology of the eye viewed as a lens instrument such as a microscope or telescope. The opposite principle, active mechanism, eclipsed but still working from the shadows, avoids the supernaturalism of the first approach by viewing agency as a primitive feature of the natural world like force or matter, an aspect of the very stuff of nature's machinery, and especially its living machinery. This competing principle informs, for example, the physiology of the eye as practiced by the nineteenth-century German physiologist and physicist Hermann von Helmholtz, who refuted the telescope analogy by arguing that

the eye was a perceiving mechanism, the functioning of which rested upon its capacity for perception.[8]

The Restless Clock follows this struggle in modern science from its inception. The story begins (chapter 1) with the lifelike machines or "automata" that spread across the landscape of late medieval and Renaissance Europe from churches to palace gardens to town squares. These machines inspired the mechanistic sciences of life that emerged in the seventeenth century through the work of intellectual radicals such as René Descartes and G. W. Leibniz. From the start, these sciences were torn between active and passive models of nature's machinery (chapters 2 and 3). The new mechanistic sciences of life in turn gave rise to a new breed of lifelike machines (chapter 4): philosophical, experimental, simulative machines that actually performed animal and human processes such as playing a flute, writing a message, breathing, bleeding, speaking, sketching. Accompanying these experimental models of living beings was a hypothetical figure, the Enlightenment man-machine or "android" (chapter 5), whose authors invoked him to propose that human beings might be material entities through and through. The authors of this thought experiment drew conclusions that were at once physiological, social, moral, economic and political.

A major development of the experiments and thought experiments of this period, the mid- to late eighteenth century, came to fruition in the work of the French naturalist Jean-Baptiste Lamarck. This development was the momentous idea that living beings might be not just active but also *self-making* and *self-transforming* machines whose structures changed over time (chapter 6). Charles Darwin, when he adopted this Lamarckian idea, inherited the active-mechanist model of life that it assumed. However, Darwin also inherited a passive-mechanist model of living beings, because this model was implicit in another idea essential to his theory, an idea that had developed within the passive-mechanist tradition of arguments from design: the notion that living creatures were perfectly "fitted" and "adapted" to their environments. Hence Darwin's theory of evolution was torn between active- and passive-mechanist models of living beings (chapter 7).

Around the turn of the nineteenth to twentieth centuries, Darwinists in the German-speaking world, negotiating the intellectual, religious, and institutional politics of the new research universities, offered a reinterpretation of Darwin's theory in which they aimed to eradicate all traces of active mechanism: a passive-mechanist neo-Darwinism (chapter 8). During the first half of the twentieth century, culminating in the decades after World War II, this neo-

Darwinist approach, officially passive-mechanist with buried strains of active mechanism, informed the philosophical, scientific and engineering movement called "cybernetics" (chapter 9) and through cybernetics, the founding of new scientific approaches and disciplines including artificial intelligence, cognitive science, and mathematical biology.

And so the old contradiction, buried in history, maintains a subterranean activity in current science. It lies at the root, for instance, of ongoing skirmishes among biologists and their critics over the appearance and implications of apparent design in nature and the role of teleology in scientific explanation. These battles have generated influential scientific approaches and principles such as Richard Dawkins's notion of the "selfish gene"[9] and Daniel Dennett's campaign to eliminate "skyhooks" (a "skyhook" being a purposeful "force or power or process") from evolutionary biology.[10] In both cases, the seventeenth-century, contradictory approach to agency in nature continues to exert a powerful seismic pressure from below the surface. The same centuries-old contradiction has been at work in the roboticist Rodney Brooks's and others' "embodied," "evolutionary," and "behavioral" approaches to artificial intelligence.[11] This book's final chapter (chapter 10) examines some instances of these recent and current scientific debates and programs in the light of their hidden history.

The philosopher and historian of science Thomas Kuhn, in his 1962 book *The Structure of Scientific Revolutions*, described science as shaped, at each stage, by a dominant "paradigm" (a model or approach). This paradigm would inform all scientific research until its limitations began to undermine it, and then a new paradigm would emerge to overthrow it, for example, the way the heliocentric (sun-centered) model of the universe overthrew the geocentric (earth-centered) model in the sixteenth to seventeenth centuries.

The story told here, in contrast, is not about a single paradigm shaping scientific research, but rather about an engagement between competing principles and approaches. The people involved in this competition have been ambivalent in their commitments, and the losing principle has not disappeared from science. Instead it has remained, obscured from view by the winning principle, but still active. Thus a conflict between two competing principles has shaped the development of modern scientific accounts of life. This book traces the development of the eclipsed scientific principle, the naturalization of agency, and its confrontations with the principle that eclipsed it, the banishment of agency from nature. To identify this struggle is to recognize intellectual possibilities that have been hidden by the course of history.

Intellectual possibilities are not the sole fruits of this investigation, though, nor could they have been, since ideas are inseparable from the world in which they arise. Social and political engagements, as well as intellectual and cultural ones, have all along been inextricable from the competition between scientific models of living and human beings. The classical brute-mechanist approach to the science of life and the active-mechanist approach have developed, as we shall see, in close conjunction with mechanical and industrial arrangements such as the automatic loom and the transformed world of production that accompanied it; with economic policies including the division of various kinds of labor; with taxonomies and rankings of human beings by sex, race, class, geographical origin, and temperament; and with projects of imperial conquest and governance. In what follows, investigating this centuries-old dialectic in science will mean uncovering the hidden action of forces that are at once intellectual and political, scientific and social.

One major purpose of *The Restless Clock* has been to demonstrate the importance of historical understanding to current thinking about the sciences of life and mind. Historical analysis, by revealing the now-hidden forces that shaped current scientific problems and principles, can reopen foreclosed ways of thinking. Investigating the origins and development of current scientific principles means rediscovering alternative possibilities for what it has meant, and what it can mean, to offer a scientific model of a living being.

Along the Route de l'Horlogerie (The Clockmaker's Way) through the Jura Mountains in Switzerland, mechanical creatures two and three centuries old remain in the alpine villages where they were first created, attended by curators and watchmakers who are often the direct descendants of the original builders. I traveled there in the course of writing this book. Among the clockwork beings I encountered is a peasant teaching his pig to hunt truffles. Holding a truffle in one hand, and his pig on his opposite knee, the peasant is apparently in the midst of explaining that you find a truffle by its smell. Raising the truffle to his nose, he inhales (his chest rises), he shakes his head from side to side, and he simultaneously closes his eyes, giving an irresistible display of sentience. The machine is strikingly persuasive. It seems to suggest that sentience and living agency might just consist of movements of passive mechanical parts. Or else it suggests that mechanical parts are anything but passive. In fact, I think it suggests both things at once. The story lies in the journey to and fro between these possibilities. If aquosity were not a compelling possibility, the joke would not have been funny.