The Scalar Stack

Free Will as the Capacity to Direct Causal Flow

Eli Adam Deutscher

Abstract

For centuries, the free will debate has been paralyzed by a false binary: either human agents possess metaphysical "uncaused causation" or we are deterministic automata. I argue that free will is not a binary property but a **scalar capacity** inherent to life itself—the capacity to redirect causal flow toward persistence. This capacity, which I term ***Hormē*** (Ὁρμή), is the constitutive drive of living systems and scales through evolutionary complexity: from bacterial taxis to human deliberation. By reframing free will as what life *does*—not what minds *have*—I dissolve the traditional stalemate and provide an empirically grounded, testable account of freedom across the tree of life. The framework yields a graduated spectrum of agency—from vegetative (plants) to reflective (human)—each with measurable degrees of causal influence. This approach naturalizes free will without reducing it, offering a unified account that respects both the laws of physics and the lived reality of choice. The result is not just a philosophical solution but a scientifically testable framework with implications for neuroscience, artificial intelligence, mental health, and ethics.

Keywords: free will, scalar agency, *Hormē*, causal flow, degrees of freedom, life-agency continuity, thermodynamics, navigation

---

1 Introduction: The Stalemate and the Biological Turn

How can we be free in a world governed by physical laws? This question—the so-called "problem of free will"—has structured Western philosophy since Aristotle. The contemporary debate remains locked in a three-way stalemate:

1. **Libertarianism** insists that genuine freedom requires **uncaused causation**—an exemption from the deterministic chain of physical events, often attributed to a non-physical mind or soul[1].
2. **Hard determinism** maintains that the universe is causally closed; what we call "choice" is an epiphenomenal illusion generated by neural machinery we do not control[2].
3. **Compatibilism** attempts a middle path, redefining free will as the capacity to act in accordance with one's desires without external coercion, even within a deterministic framework[3].

Despite their differences, all three positions share a tacit premise: that free will is a **special property of conscious minds**, relevant only to humans or at most to animals with sophisticated cognition. This anthropocentric framing has produced a debate that is at once intellectually sterile and existentially unsatisfying—a debate that cannot be resolved because it begins too late, with the human case, rather than at the beginning: with life itself.

In this paper, I argue that to understand human free will, we must first understand what **agency** is in its most minimal form. Drawing on thermodynamics, evolutionary biology, and the logic of self-maintaining systems, I demonstrate that **minimal free will is identical to minimal agency**: the capacity of a living system to redirect causal flow toward its own persistence. This capacity is not an evolved luxury or a metaphysical mystery; it is the **constitutive condition of bounded existence in a lawful reality**. I term this constitutive drive ***Hormē*** (Ὁρμή)—the goal-directed striving that defines being alive.

The argument proceeds as follows. Section 2 briefly maps the historical landscape of the free will debate, showing how it became disconnected from biology. Section 3 introduces the core concepts: ***Hormē*** as the thermodynamic imperative to persist, and **directing causal flow** as its behavioral expression. Section 4 establishes the bacterial paradigm—Degree 0 agency—as the foundation. Section 5 elaborates the **scalar stack** of freedom across the tree of life, from plants

[1] See Roderick M. Chisholm, "Human Freedom and the Self," *The Lindley Lecture*, University of Kansas, 1964, 3–15 for the classic defense of agent-causation.

[2] For the comprehensive argument regarding the "illusion" of conscious will, see Daniel M. Wegner, *The Illusion of Conscious Will* (MIT Press, 2002).

[3] See Daniel C. Dennett, *Freedom Evolves* (Viking, 2003) for a seminal evolutionary account of compatibilism.

and insects to mammals, primates, and finally humans. Section 6 explains why this thermodynamic-biological account dissolves the traditional stalemate. Sections 7–9 develop testable predictions, implications for moral responsibility and artificial intelligence, and replies to major objections.

The result is a **naturalized, scalar theory of free will** that is both empirically grounded and phenomenologically adequate. It shows that freedom is not something we *have* in spite of being physical systems, but something we **are** because we are living systems engaged in the continuous work of navigating reality. The question shifts from "Do we have free will?" to "What degree of freedom do we wield, and to what end?"

2 The Landscape: A Brief History of a Stalled Debate

To understand why the free will debate has remained intractable, we must examine how it became divorced from the biological reality of agency. What began as a question about the nature of voluntary action gradually transformed into a metaphysical puzzle about mind and causality—a puzzle that could not be solved because its premises ignored the very phenomenon it sought to explain: life itself.

2.1 Ancient Foundations: From Action to Mind

The problem of free will did not begin as a problem about "free will" per se. In Aristotle's ethics, the central distinction was between *voluntary* (ἑκούσιος) and *involuntary* (ἀκούσιος) action. An action was voluntary if its origin (*archē*) was within the agent[4]. This was a **causal and psychological criterion**, not a metaphysical one: could the agent have acted otherwise given their character and circumstances? Aristotle's analysis remained grounded in the **nature of living beings**—their capacities for desire (*orexis*), deliberation (*bouleusis*), and choice (*prohairesis*).

With Augustine, the terrain shifted. Wrestling with the problem of sin and divine foreknowledge, Augustine located the will (*voluntas*) in the soul's movement toward or away from God[5]. The will became a **faculty of a non-physical substance**, setting the stage for the mind-body dualism that would come to dominate the debate.

2.2 The Modern Impasse: The Ghost in the Machine

The Cartesian revolution cemented the dualist framework. For Descartes, the mind (*res cogitans*) was a thinking substance utterly distinct from the extended substance of the body (*res extensa*). Free will belonged to the mind alone; it was the capacity to affirm or deny ideas, to pursue or avoid goods, independently of mechanical causation[6]. This created the **exemption problem**:

[4]Aristotle, *Nicomachean Ethics*, trans. T. Irwin (Hackett Publishing, 1999), III.1–5.
[5]Augustine, *The City of God Against the Pagans*, trans. R. W. Dyson (Cambridge University Press, 1998), XIV.6.
[6]René Descartes, *Meditations on First Philosophy*, trans. J. Cottingham (Cambridge University Press, 1986), IV.

how could a non-physical mind interact with a physical body without violating the conservation of energy? Descartes' infamous pineal gland hypothesis was less a solution than an admission of the problem's intractability.

The Enlightenment responses deepened the stalemate. Hume, committed to a Newtonian universe of efficient causes, rejected Cartesian dualism but retained the anthropocentric focus. His compatibilism defined liberty as "a power of acting or not acting, according to the determinations of the will"—that is, the absence of external constraint[7]. This was a **negative, human-centered definition** that said nothing about what agency *is*, only when it is unimpeded. Kant, recognizing the moral stakes, posited "transcendental freedom" as a necessary postulate of practical reason—a causality beyond nature that we must presuppose to make sense of moral responsibility[8]. This saved morality at the cost of placing freedom in the **unknowable noumenal realm**, forever beyond scientific inquiry.

2.3 The 20th-Century Stalemate: Refining the Deadlock

The 20th century saw the debate crystallize into the three positions that define the contemporary landscape.

Libertarians like Roderick Chisholm argued that human agents are "prime movers unmoved"—uncaused causers whose volitions intrude into the physical causal order[9]. This position preserved the intuition of ultimate responsibility but at the cost of positing a **causal singularity** that violates the principle of sufficient reason and remains empirically unverifiable.

Hard determinists, drawing on neuroscience and psychology, argued that conscious will is an after-the-fact confabulation. Benjamin Libet's experiments suggesting neural preparation for movement before conscious intention became a rallying point[10]. Daniel Wegner systematized this into the "illusion of conscious will" thesis, arguing that the feeling of agency is a post-hoc narrative constructed by the brain[11]. This position respects the causal closure of physics but **denies the evident reality of goal-directed action** across the biological world.

Compatibilists, led by figures like Harry Frankfurt and Daniel Dennett, attempted to salvage freedom within a naturalistic framework. Frankfurt's hierarchical model defined a person as free when their first-order desires align with their second-order volitions[12]. Dennett reframed free

[7] David Hume, *An Enquiry Concerning Human Understanding*, ed. T. L. Beauchamp (Oxford University Press, 2000), §VIII.

[8] Immanuel Kant, *Critique of Pure Reason*, trans. P. Guyer and A. W. Wood (Cambridge University Press, 1998), A533/B561.

[9] See Chisholm, "Human Freedom and the Self".

[10] See Benjamin Libet, "Unconscious Cerebral Initiative and the Role of Conscious Will in Voluntary Action," *Behavioral and Brain Sciences* 8, no. 4 (1985): 529–39.

[11] See Wegner, *The Illusion of Conscious Will*.

[12] See Harry G. Frankfurt, "Freedom of the Will and the Concept of a Person," *The Journal of Philosophy* 68, no. 1 (1971): 5–20.

will as an evolved capacity for self-control and foresight—a "user illusion" that is nonetheless real in its consequences[13]. While more biologically informed, compatibilism often remained **human-exceptionalist**, focusing on linguistic, reflective, and social capacities without explaining their roots in simpler forms of agency.

2.4 The Missing Foundation: Agency Before Consciousness

The common thread across all three traditions is the **focus on conscious, human-level deliberation**. The debate asks: "Can a *conscious mind* originate action?" This question presupposes that agency begins with consciousness. But life on Earth existed for billions of years before consciousness emerged. Bacteria navigate chemical gradients; plants grow toward light; insects avoid predators—all without consciousness. These systems are **unambiguously agents**: they sense, process, and act to maintain their existence.

By ignoring this vast domain of **minimal agency**, the philosophical debate became a narrow conversation about a highly derived, late-evolving feature of one species. It is as if a theory of locomotion began with ballet, ignoring walking, crawling, and swimming. To make progress, we need a **biological turn**: we must ground the theory of free will in a theory of agency that applies to all living systems. The question is not first "Are humans free?" but "What does it mean for any living system to be a source of goal-directed action?" The answer to that question will reveal that freedom is not a metaphysical add-on, but the **operational signature of being alive**.

3 The Core Mechanism: *Hormē* and Directing Causal Flow

If free will is not a ghost in the machine, but a way of being in the world, we must identify the constitutive feature that distinguishes living agents from non-living objects. That feature is ***Hormē*** (Ὁρμή)—the drive to persist—and its behavioral expression: **directing causal flow**. This section defines these core concepts and shows how they jointly constitute minimal agency, and therefore minimal free will.

3.1 *Hormē*: The Constitutive Drive of Living Systems

Hormē is not a metaphor for "wanting" or "trying." It is the **physically grounded, goal-directed imperative** of a bounded organization to maintain itself against dissolution. In the Neo-Pre-Platonic Naturalism (NPN) framework from which this term is adopted, *Hormē* is a First Principle: the non-negotiable ground of being an agent[14]. Every living system, from bacterium to human, possesses *Hormē*; to cease to strive is to cease to be that living entity.

Thermodynamically, *Hormē* manifests as the continuous work required to maintain a **far-from-equilibrium state** against the entropic gradient. As complexity theorists have

[13] See Dennett, *Freedom Evolves*.

[14] See Eli Adam Deutscher, *Neo-Pre-Platonic Naturalism* (Neo-Pre-Platonic Press, 2025), 53.

shown, this capacity for self-organization at the "edge of chaos" is the hallmark of life[15]. A living cell maintains ion gradients across its membrane; a multicellular organism regulates its internal temperature and chemistry; a human sustains metabolic, psychological, and social structures. All are instances of the same constitutive imperative: **persist or dissolve**. This is not a matter of preference but of physical necessity: a bounded low-entropy state in a higher-entropy environment requires continuous energy flow to maintain[16]. This bioenergetic reality underpins all cellular function, from ion pumping to motility[17].

Hormē is therefore **scale-invariant** but **complexity-variant**. In a bacterium, it is expressed through immediate metabolic and locomotor responses. In a human, it is filtered through layered psychological faculties—*Orexis* (appetite), *Thymos* (social-strategic emotion), *Logistikon* (executive calculation), and *Nous* (abstract modeling)—but the underlying drive remains the same[18]. *Hormē* is the "why" behind action: the ultimate reason any living system does anything.

3.2 Directing Causal Flow: The Behavioral Expression of *Hormē*

If *Hormē* is the internal imperative, **directing causal flow** is its external, observable signature. To direct causal flow is to **expend energy to alter the probable future trajectory of events** in a way that serves the system's persistence.

Consider a bacterium in a chemical gradient:

- **Without action:** Diffusion and Brownian motion would carry it randomly. Its future location is probabilistically distributed.
- **With action:** It engages its flagellar motor, burning ATP to swim toward higher nutrient concentration. It **biases the probability distribution** of its future location toward regions that support its metabolism.

This biasing is not a violation of physics; it is an **exploitation of physics**. The bacterium uses energy to convert a less probable future (being in a nutrient-rich zone) into a more probable one. It **redirects the causal flow** that would otherwise lead to dissolution.

Contrast this with a rock rolling down a hill:

- The rock is **carried by** causal flow (gravity, friction, initial conditions).
- The bacterium **intervenes in** causal flow.

[15] See Stuart A. Kauffman, *The Origins of Order: Self-Organization and Selection in Evolution* (Oxford University Press, 1993).

[16] See Harold J. Morowitz, *Energy Flow in Biology* (Academic Press, 1968); see also Erwin Schrödinger, *What Is Life? The Physical Aspect of the Living Cell* (Cambridge University Press, 1944) and G. Nicolis and I. Prigogine, *Self-Organization in Nonequilibrium Systems* (Wiley, 1977).

[17] See David G. Nicholls and Stuart J. Ferguson, *Bioenergetics*, 4th ed. (Academic Press, 2013).

[18] See Deutscher, *Neo-Pre-Platonic Naturalism*, Chap. 6.

This distinction—between **being a conduit** of causality and **being a director** of causality—is the fundamental divide between non-living objects and living agents. Directing causal flow is what agents *do*; it is the macroscopic behavior that reveals the microscopic reality of *Hormē*.

3.3 Agency as *Hormē* in Action

We can now state the core identity:

Agency is *Hormē* expressed through the redirection of causal flow.

This definition is **minimalist** and **non-anthropocentric**. It does not require consciousness, representation, or even a nervous system. It requires only:

1. A bounded organization that must work to maintain itself (*Hormē*).
2. The capacity to expend that work to alter probable futures (directing causal flow).

A plant bending toward light is an agent. A worm retreating from touch is an agent. A bee navigating to a flower is an agent. Each redirects causal flow—of photons, of physical pressure, of spatial location—toward states that support persistence.

Free will, in its minimal form, is precisely this capacity to redirect causal flow. It is not first and foremost about choosing between chocolate and vanilla, or about moral responsibility; it is about swimming up the gradient when the current pulls you down. What we call "free will" in humans is a highly elaborated, conscious, and socially mediated version of this same basic capacity. By starting here, at the bacterial level, we establish a **continuous, scalable foundation** for understanding freedom across the whole tree of life.

4 The Bacterial Paradigm: Minimal Agency as Minimal Free Will

If agency is *Hormē* expressed through causal redirection, then the simplest living system provides the clearest lens through which to see free will in its pure, unadorned form. The bacterium—lacking nerves, brain, or consciousness—nonetheless exhibits the constitutive features of agency. What it does is not a metaphor for freedom; it *is* freedom, at its most foundational degree. This section establishes the bacterial paradigm as Degree 0 in the scalar stack of free will.

4.1 What a Bacterium Does

Consider *Escherichia coli* in a gradient of glucose. Through a process called chemotaxis—foundationaly characterized by Adler[19]—the bacterium detects chemical concentrations via membrane receptors. It processes this information through a sophisticated signal-transduction network and actuates its flagellar motor to bias its movement[20]. When it senses increasing attractant concentration, it suppresses tumbling and swims in longer runs; when concentration decreases, it tumbles more frequently to reorient. The result is a **biased random walk** that probabilistically leads it toward nutrient sources and away from toxins.

This behavior meets the criteria for agency:

1. ***Hormē*:** The bacterium maintains a far-from-equilibrium state through continuous metabolism. Its activity serves that persistence.
2. **Directing causal flow:** By burning ATP to actuate its flagella, it alters the probability distribution of its future location. Without this expenditure, diffusion and currents would determine its path. With it, the bacterium **biases outcomes** toward nutrient acquisition.

The bacterium does not "represent" the glucose or "decide" in any conscious sense. Its "choice" is an automatic, chemical-mechanical response. Yet that response is **goal-directed** (*Hormē*) and **causally effective** (redirecting flow). This is agency in its minimal form.

4.2 The Freedom in Biased Motion

What, then, is the bacterium "free" from or "free" to do? It is **free from being merely carried by external flows**. It is **free to expend its own energy to change its trajectory**. This is a **positive, physical freedom**—the freedom to act as a source of causation, not merely a conduit.

This freedom is **measurable**. We can quantify:

- The **energy cost** per unit of biased displacement (ATP consumed).
- The **efficiency** of gradient-climbing compared to passive diffusion.
- The **reliability** with which the bacterium reaches nutrient sources under varying conditions.

These are not metaphorical liberties; they are physical parameters of a navigation system. The bacterium's "free will" is its capacity to navigate its chemical environment using self-generated work. That capacity is what keeps it alive.

[19] See Julius Adler, "Chemotaxis in Bacteria," *Science* 153, no. 3737 (1966): 708–16.

[20] See George H. Wadhams and Judith P. Armitage, "Making Sense of It All: Bacterial Chemotaxis," *Nature Reviews Microbiology* 2, no. 12 (2004): 1024–37 for a modern synthesis; see also Howard C. Berg and Douglas A. Brown, "Chemotaxis in *Escherichia Coli* Analysed by Three-Dimensional Tracking," *Nature* 239, no. 5374 (1972): 500–504.

4.3 Objection: "But It's Just a Mechanism!"

A common response is to dismiss bacterial chemotaxis as "merely mechanistic"—a deterministic biochemical cascade that leaves no room for "real" freedom. This objection misunderstands both mechanism and freedom.

First, **all agency is mechanistic**. Human deliberation is also a mechanism—an enormously complex one involving neural networks, neurotransmitter dynamics, and predictive processing. The difference is one of **complexity**, not **kind**. To deny agency to the bacterium because its mechanism is simple is to commit a **fallacy of origins**: believing that what comes from simple causes cannot be genuine.

Second, the objection assumes that freedom requires **exemption from mechanism**. But as established in Section 3, freedom is not exemption; it is **a specific mode of mechanical operation**: the mode where the system's own organization harnesses energy to bias outcomes. The bacterium is not less free because its mechanism is deterministic; it is free *in virtue of* having a mechanism that redirects causal flow.

4.4 Degree 0 Freedom: A Summary

Degree 0 freedom is characterized by:

- **System:** Single-celled organisms (bacteria, archaea, some protists).
- **Mechanism:** Direct sensor-effector coupling via biochemical networks.
- **Time-scale:** Immediate (seconds).
- **Freedom:** Binary or probabilistic bias toward/away from stimuli.
- **Example:** *E. coli* climbing a glucose gradient.

This is where free will begins. Not with introspection, not with moral reasoning, but with **metabolism-driven navigation**. Every other form of freedom in the tree of life is an elaboration of this basic capacity. By starting here, we establish a **continuous ontological foundation**: human free will is not a different *kind* of thing, but a vastly more complex **degree** of the same thing.

The bacterial paradigm does not diminish human freedom; it **grounds** it. It shows that what we experience as choice, will, and autonomy has a billion-year-old physical basis. We are not ghosts in machines; we are extremely sophisticated descendants of swimmers in chemical gradients.

---

5 The Scalar Stack: Degrees of Freedom Across the Tree of Life

A note on taxonomy: The degrees outlined below are **conceptual landmarks**, not rigid taxonomic categories. Nature presents gradients, hybrids, and edge cases (e.g., slime molds, venus

flytraps, octopuses). The purpose of the stack is not to classify every species definitively, but to illustrate the **continuous expansion of causal-redirection capacity** along the axes of sensorimotor complexity, temporal horizon, and model fidelity. The boundaries are fuzzy; the continuum is real.

Freedom is not a binary switch that flickers on only in conscious minds. It is a **scalar capacity** that deepens and diversifies as living systems evolve greater complexity in sensing, modeling, and acting. From the immediate bias of a bacterium to the decades-spanning projects of a human, the same constitutive imperative—*Hormē* expressed through causal redirection—manifests across a continuum of sophistication. This section maps that continuum, identifying five distinct degrees of freedom observable in the natural world.

5.1 Degree 1: Vegetative Agency — The Freedom of Growth and Allocation

Before nervous systems, there was growth. Plants, fungi, and many sessile organisms exhibit agency through **tropisms** and **resource-foraging strategies** that redirect causal flow on physiological and developmental timescales.

5.1.1 The Mechanisms of Vegetative Freedom

- **Phototropism/Gravitropism:** Differential cell elongation bends stems toward light or roots downward[21].
- **Root foraging:** Root systems proliferate in nutrient-rich soil patches while avoiding compacted or toxic zones[22].
- **Chemical signaling:** Mycelial networks coordinate growth and resource distribution across vast areas without a central nervous system[23].
- **Plant Communication:** As recent research suggests, plants actively assess their neighbors and kin, altering morphology in response to competitive signals[24]. Some theorists argue this constitutes a form of "plant intelligence," or adaptive problem-solving without a brain[25].

5.1.2 What Freedom Means Here

A tree root navigating around a rock is **redirecting the causal flow of its own growth** to secure water. A vine climbing a trellis is **biasing its structural development** toward light capture. This freedom is:

[21] See Charles Darwin, *The Power of Movement in Plants* (John Murray, 1880).

[22] See Angela Hodge, "Root Decisions," *Plant, Cell & Environment* 32, no. 6 (2009): 628–40.

[23] See Suzanne W. Simard et al., "Net Transfer of Carbon Between Ectomycorrhizal Tree Species in the Field," *Nature* 388, no. 6642 (1997): 579–82.

[24] See Richard Karban, "Plant Behaviour and Communication," *Ecology Letters* 11, no. 7 (2008): 727–39.

[25] See Anthony Trewavas, "Aspects of Plant Intelligence," *Annals of Botany* 92, no. 1 (2003): 1–20.

- **Slow:** Unfolds over hours to seasons.
- **Distributed:** No central controller; agency emerges from cellular-level responses.
- **Persistent:** The "choice" is literally embodied in altered morphology.

Example: An oak tree allocates more resources to branches in the sunlit canopy while letting shaded limbs die back. It is **shaping its own future form** to optimize energy capture—a vegetative expression of *Hormē*.

5.2 Degree 2: Reactive Agency — The Freedom of Reflex and Fixed Action Patterns

With the evolution of nervous systems, agency gains speed and specificity. Insects, arachnids, worms, and many other invertebrates exhibit **modular, stimulus-driven responses** that are rapid, repeatable, and often modifiable by experience.

5.2.1 The Mechanisms of Reactive Freedom

- **Reflex arcs:** Hard-wired sensorimotor circuits (e.g., cockroach escape response).
- **Fixed action patterns:** Stereotyped sequences released by specific sign-stimuli (e.g., web-building in spiders).
- **Associative learning:** Classical and operant conditioning allow organisms to predict environmental contingencies[26].

5.2.2 What Freedom Means Here

A fly avoiding a swatter is **redirecting its flight path** based on visual expansion cues. An ant following a pheromone trail is **biasing its locomotion** toward a food source. This freedom is:

- **Fast:** Millisecond to second responses.
- **Modular:** Dedicated circuits for specific ecological challenges.
- **Conditionable:** Past outcomes can alter future responses.

Example: A bee, after being deterred by a predator at one flower patch, avoids that patch and seeks another. Its **behavioral repertoire is updated** by experience, allowing it to navigate a risky foraging landscape more effectively.[27]

[26] See Tim Tully et al., "Gene Disruption of Learning and Memory: A Structure-Function Perspective," *Cell* 79, no. 1 (1994): 35–47 on fruit fly learning; see Thomas J. Carew and Christie L. Sahley, "Invertebrate Learning and Memory: From Behavior to Molecules," *Annual Review of Neuroscience* 9, no. 1 (1986): 435–87 for a review of invertebrate learning mechanisms.

[27] For evidence of predator avoidance learning and the trade-off between foraging efficiency and safety in bees, see Ken Tan et al., "Imidacloprid Alters Foraging and Decreases Bee Avoidance of Predators," *PLoS ONE* 9, no. 7 (2014): e102725, https://doi.org/10.1371/journal.pone.0102725.

5.3 Degree 3: Emotional Agency — The Freedom of Valenced Action Selection

Mammals, birds, and some reptiles possess neural architectures that support **internal affective states**—fear, desire, curiosity, rage—which modulate decision-making in flexible, context-sensitive ways[28]. These are not just reactions; they are **action-selection systems** filtered through embodied value.

5.3.1 The Mechanisms of Emotional Freedom

- **Limbic system:** Neural substrates for reward, aversion, and social bonding. Specifically, the amygdala circuitry integrates sensory inputs to orchestrate defensive responses to threat[29].
- **Play and exploration:** Intrinsically motivated behavior that builds competence and models the world.
- **Social learning:** Imitation, emulation, and teaching within groups.

5.3.2 What Freedom Means Here

A rat choosing between exploring a novel maze arm or returning to a known food site is **weighing curiosity against safety**. A dog suppressing the urge to chase a squirrel when commanded is **inhibiting a prepotent response** in favor of social reward. This freedom is:

- **Affectively colored:** Choices are "hot," infused with emotional tone.
- **Socially embedded:** Behavior is shaped by dominance, attachment, and cooperation.
- **Time-extended:** Can involve patience, delay, and simple planning.

Example: A crow using a car to crack a nut by placing it on a road and waiting for traffic. This involves **tool use, causal understanding, and delayed gratification**—a flexible orchestration of action toward a deferred goal.[30]

5.4 Degree 4: Deliberative Agency — The Freedom of Mental Simulation

Great apes, cetaceans, elephants, and some corvids exhibit the capacity for **off-line mental simulation**: representing possible futures, inferring others' perspectives, and selecting actions based on those models[31].

---

[28] See Jaak Panksepp, *Affective Neuroscience: The Foundations of Human and Animal Emotions* (Oxford University Press, 1998) for the definitive text on affective neuroscience.

[29] See Joseph LeDoux, "Rethinking the Emotional Brain," *Neuron* 73, no. 4 (2012): 653–76.

[30] This behavior, often cited as a prime example of avian innovation, is a sophisticated variant of the nut-dropping and anvil-use strategies documented in corvids; see W. C. McGrew, "Is Primate Tool Use Special? Chimpanzee and New Caledonian Crow Compared," *Philosophical Transactions of the Royal Society B: Biological Sciences* 368, no. 1630 (2013): 20120422, https://doi.org/10.1098/rstb.2012.0422 for a comparative analysis of corvid and primate tool use.

[31] See Josep Call and Michael Tomasello, *Primate Cognitive Systems* (Oxford University Press, 2010).

5.4.1 The Mechanisms of Deliberative Freedom

- **Prefrontal cortex (or analogue):** Enables working memory, inhibitory control, and planning.
- **Theory of mind:** Attributing mental states to others (e.g., tactical deception in chimpanzees).
- **Episodic-like memory & Foresight:** The ability to recall specific past events informs "mental time travel" into the future, allowing agents to act now for the sake of a future need[32].

5.4.2 What Freedom Means Here

A chimpanzee hiding a stone behind its back before a dominance confrontation is **simulating what another will see and planning accordingly**. An orangutan testing multiple stick tools to extract honey is **running mental trials** before physical commitment.[33] This freedom is:

- **Representational:** Actions are chosen based on internal models.
- **Strategic:** Can involve deception, cooperation, and long-term social maneuvering.
- **Creative:** Novel solutions emerge from recombination of past experiences.

Example: A dolphin cooperating with fishermen by herding fish toward their nets, then feasting on the escapees. This is **interspecies coordination based on inferred goals**—a high-degree navigation of a social-ecological niche.[34]

5.5 Degree 5: Reflective Agency — The Freedom of Self-Modeling and Normative Governance

Humans alone (so far as we know) possess the capacity for **explicit self-modeling** and **normative self-governance**. We do not merely choose actions; we choose **who to be**, according to values, principles, and life-projects that we can articulate, critique, and revise.

[32]See Nicola S. Clayton et al., "Social Cognition by Food-Caching Corvids. The Western Scrub-Jay as a Natural Psychologist," *Philosophical Transactions of the Royal Society B: Biological Sciences* 362, no. 1480 (2007): 507–22; see also Thomas Suddendorf and Michael C. Corballis, "The Evolution of Foresight: What Is Mental Time Travel, and Is It Unique to Humans?" *Behavioral and Brain Sciences* 30, no. 3 (2007): 299–313.

[33]For the documentation of spontaneous planning and deceptive object concealment in chimpanzees (e.g., the case of Santino), see Mathias Osvath, "Spontaneous Planning for Future Stone Throwing by a Male Chimpanzee," *Current Biology* 19, no. 5 (2009): R190–91, https://doi.org/10.1016/j.cub.2009.01.010; see also Katja Karg et al., "Chimpanzees Strategically Manipulate What Others Can See," *Animal Cognition* 18 (2015): 1069–76, https://doi.org/10.1007/s10071-015-0875-z for experimental evidence of strategic manipulation of visual access.

[34]This famous population of "cooperative" dolphins in Laguna, Brazil, has been extensively studied; the behavior is culturally transmitted and shapes the dolphins' social structure. See F. G. Daura-Jorge et al., "The Structure of a Bottlenose Dolphin Society Is Coupled to a Unique Foraging Cooperation with Artisanal Fishermen," *Biology Letters* 8, no. 5 (2012): 702–5, https://doi.org/10.1098/rsbl.2012.0174.

5.5.1 The Mechanisms of Reflective Freedom

- ***Nous* (abstract modeling):** Capacity for symbolic thought, counterfactual reasoning, and hypothetical planning.
- ***Logistikon* (executive governance):** The ability to resolve conflicts between lower-level drives (*Orexis*, *Thymos*) under the guidance of higher-order principles[35].
- **Metacognition:** The capacity to monitor and control one's own cognitive processes[36]. It enables us to know *that* we are thinking and evaluate the quality of that thought[37].
- **Moral imagination:** Considering how actions affect others' *Hormē* across expanding circles of concern.

5.5.2 What Freedom Means Here

A human donating a kidney to a stranger is **acting from a consciously adopted ethical identity**. A scientist abandoning a favored hypothesis in the face of evidence is **submitting personal attachment to the normative authority of truth**. This freedom is:

- **Self-reflexive:** We can think about our own thinking, question our own motives.
- **Normatively structured:** Guided by "oughts" that are examined, not just felt.
- **Temporally vast:** Can span a lifetime or generations (e.g., building an institution, writing a constitution).

Example: Socrates choosing hemlock over exile, declaring that "the unexamined life is not worth living." This is **freedom exercised at the highest degree**: redirecting the ultimate causal flow—one's own existence—in accordance with a consciously embraced ideal.[38]

5.6 The Continuum in Perspective

This scalar stack is not a ladder of moral worth but a **map of navigational complexity**. Each degree represents an expansion in:

- **Temporal horizon** (seconds → seasons → decades)
- **Model fidelity** (direct sensing → affective appraisal → symbolic simulation)
- **Causal leverage** (biasing locomotion → shaping ecosystems → steering civilizations)

[35] See Deutscher, *Neo-Pre-Platonic Naturalism*, 69.

[36] See Janet Metcalfe and Arthur P. Shimamura, eds., *Metacognition: Knowing about Knowing* (MIT Press, 1994).

[37] See Peter Carruthers, "How We Know Our Own Minds: The Relationship Between Mindreading and Metacognition," *Behavioral and Brain Sciences* 32, no. 2 (2009): 121–38.

[38] Plato, *Apology*, 38a. This famous declaration marks the transition to Degree 5 agency: the capacity to subject one's own *Hormē* to normative interrogation.

Yet at every level, the core identity holds: **agency = *Hormē* expressed through causal redirection**. The bacterium and the philosopher are engaged in the same fundamental project—persisting by reshaping the world—differing only in the tools at their disposal.

This continuity demystifies free will without diminishing it. Human freedom is not a metaphysical anomaly; it is **Degree 5 of a property that life has always possessed**. We are not less free because bacteria are somewhat free; we are **more capable** of directing causal flow across more dimensions, over longer spans, with greater foresight. The task of ethics, education, and self-cultivation is to wield that capacity wisely.

6 The Thermodynamic Engine: Why *Hormē* Is Physical, Not Metaphysical

The scalar stack described in Section 5 is not merely a descriptive taxonomy—it is grounded in the physics of energy and organization. Each degree of freedom corresponds to a **specific thermodynamic configuration** that enables increasingly sophisticated modes of causal redirection. This section clarifies the relationship between the metaphysical concept of *Hormē* and its physical manifestation in far-from-equilibrium systems, showing why this naturalized account **dissolves rather than answers** the traditional free will debate.

6.1 Life as a Far-from-Equilibrium Process

At its most fundamental, a living system is a **localized reduction of entropy** maintained against the universal gradient of dispersal. Erwin Schrödinger captured this famously: life "feeds on negative entropy," importing free energy to sustain its ordered state while exporting disorder to its surroundings[39]. This is not a metaphor but a **physical necessity**: a bounded, low-entropy organization in a higher-entropy environment requires continuous work to prevent dissolution.[40]

6.2 The Energy Cost of Freedom

Every degree of freedom in the scalar stack carries a measurable **energy overhead**. More sophisticated agency requires greater metabolic investment:

Degree	System Class	Metabolic Investment (Mechanism)
0	Bacterial	**ATP hydrolysis** for flagellar motor rotation.
1	Vegetative	**Photosynthate allocation** (chemical potential) for root proliferation and stem bending.
2	Reactive	**Action potentials** and muscle contraction for reflex/escape responses.

[39]See Schrödinger, *What Is Life? The Physical Aspect of the Living Cell.*

[40]Plato, *Apology*, 38a. This famous declaration marks the transition to Degree 5 agency: the capacity to subject one's own *Hormē* to normative interrogation.

Degree	System Class	Metabolic Investment (Mechanism)
3	Emotional	**Limbic/Neurohormonal arousal** (e.g., amygdala activation) during social evaluation.
4	Deliberative	**Prefrontal Cortical glucose metabolism** during inhibition and working memory tasks.
5	Reflective	**Default Mode Network (DMN) energy expenditure** during abstract self-modeling.

Freedom is not free. It is **purchased with metabolism**. This explains why severe calorie restriction impairs decision-making, why hypoglycemia leads to poor judgment, and why cognitive fatigue follows prolonged deliberation. The feeling of "effort" in choosing is the **somatic feedback of thermodynamic expenditure**. What libertarians mistake as the "weight of freedom" is, in physical terms, the **energy cost of redirecting causal flow**.

6.3 Why This Dissolves the Traditional Debate

The tripartite stalemate outlined in Section 2 arises from a shared but flawed assumption: that free will must be either an **exception to physics** (libertarianism), an **illusion within physics** (hard determinism), or a **reconcilable feature of psychological description** (compatibilism). The biological-thermodynamic account **rejects the framing itself** by showing that agency is not something that needs to be "fit into" physics—it is **what certain physical systems do**.

6.3.1 Against Libertarianism

Libertarianism seeks a **causal exemption**—a break in the physical chain that allows an uncaused cause. But the bacterial paradigm shows that agency does not require exemption; it requires **energy-driven intervention**. The bacterium does not violate thermodynamics; it **harnesses** thermodynamics to swim. Human freedom is not different in kind, only in degree. The quest for metaphysical exemption is a **category error**—it looks for freedom *outside* the causal order when freedom is a **specific mode of operating within it**.

6.3.2 Against Hard Determinism

Hard determinism asserts that because physics is causally closed, agency is an illusion. This commits a **resolution error**: it treats all physical causation as identical, failing to distinguish between **passive conduits** and **active engines**.

Consider a rock and a bird caught in the same gust of wind.

- **The Rock:** Its trajectory is determined entirely by external forces (gravity, wind resistance). It is a **passive conduit** of causal flow.

- **The Bird:** Its trajectory is determined by external forces *plus* its internal expenditure of ATP to actuate wings and fight the wind. It is a **thermodynamic engine** that introduces a new vector of force.

Hard determinism is "blind" to this distinction. It correctly notes that both the rock and the bird obey physics, but incorrectly concludes that their relationship to physics is the same. To claim agency is illusory because it is physical is to claim that **work** is illusory because it follows laws. The bird does not violate physics; it **exploits** physics to redirect outcomes. By collapsing the distinction between *being pushed* and *pushing back*, Hard Determinism fails to describe the observable reality of living systems.

6.3.3 Against Compatibilism

Compatibilism attempts to salvage "free will" by redefining it as action aligned with one's desires, absent external coercion. While more naturalistic, this approach remains **human-centric and psychologically shallow**. It does not explain where desires come from (they are expressions of *Hormē*), nor does it account for the **scalar nature of agency** across species. More importantly, it accepts the deterministic framing and tries to carve out a semantic space for freedom within it—a defensive, rather than foundational, move. The thermodynamic account shows that freedom is not a **label we apply to certain human behaviors** but a **physical capacity with deep biological roots**.

6.4 A New Question: Not "Free or Not?" but "Free to What Degree?"

The traditional question—"Do we have free will?"—presupposes a yes-no answer. But if free will is scalar and grounded in thermodynamics, the better question is:

> **"What degree of causal redirection is this system capable of, and how is that capacity implemented?"**

This question is:

- **Empirical:** It can be investigated through biology, neuroscience, and thermodynamics.
- **Scalar:** It accommodates the continuum from bacteria to humans.
- **Productive:** It leads to testable hypotheses about energy, complexity, and behavior.

The debate dissolves because the original problem was mis-posed. We are not struggling to fit a square peg (free will) into a round hole (deterministic physics). We are recognizing that **the peg and the hole are made of the same material**—energy, matter, organization—and that agency is one of the shapes that material can take.

6.5 Interim Conclusion: Freedom as Thermodynamic Achievement

Freedom is not a ghost in the machine, nor a user-illusion, nor a metaphysical postulate. It is **what far-from-equilibrium systems do to stay far-from-equilibrium**. From the bacterium's biased random walk to the human's moral choice, the thread is continuous: life persists by **doing work to shape its future**.

The feeling of freedom is the conscious experience of that work. The capacity for freedom is the evolutionary refinement of that work into ever-more-effective forms of navigation. The problem of free will is solved not by answering the old question, but by **asking a new one**: not "Are we free?" but "How are we free, and what shall we do with that freedom?"

7 Testable Predictions: The Empirical Footprint of Scalar Freedom

A theory that cannot be tested is merely a story. The scalar, thermodynamic account of free will advanced here makes specific, falsifiable predictions across multiple domains—from microbiology to neuroscience, psychology to artificial intelligence. This section outlines those predictions, demonstrating that the framework is not just philosophically coherent but **empirically accountable**.

7.1 Prediction 1: The Metabolic-Agency Correlation

If agency—and thus minimal free will—is grounded in the capacity to expend energy to redirect causal flow, then we should observe a **quantifiable relationship between metabolic rate and the frequency/amplitude of causal redirection** across species and contexts.

7.1.1 Specific Tests:

- **Within-species:** Individuals with transiently elevated metabolic rates (e.g., via temperature manipulation within viable range) should exhibit faster/more decisive responses to the same navigational challenge (e.g., time-to-navigate a glucose gradient). This controls for evolved trade-offs by testing the same genotype under different energetic conditions.
- **Across-species:** When controlling for body size and ecology, species with higher mass-specific metabolic rates should show greater behavioral flexibility and more interventions in their environments (e.g., comparing birds to similarly-sized reptiles).
- **Pathological cases:** Conditions that impair cellular energy production (e.g., mitochondrial dysfunction) should produce measurable deficits in agentive capacity—not just "weakness" but **reduced efficacy in redirecting causal flow** (e.g., slower learning, poorer decision-making, diminished exploratory behavior).

7.2 Prediction 2: The Energy-Budget of Decision-Making

If "effortful" choice is the somatic experience of thermodynamic work, then **metabolically costly decisions should be reflected in measurable energy expenditure**, and energy depletion should impair high-degree freedom before low-degree freedom.

7.2.1 Specific Tests:

- **Neuro-energetics:** Decisions involving conflict resolution (e.g., Stroop tasks, moral dilemmas) should produce detectable increases in cerebral glucose consumption, localized to regions implicated in executive function and value-weighting[41].
- **Subjective Effort as Opportunity Cost:** The sensation of "mental effort" has been modeled as an opportunity cost signal, restricting task performance when the metabolic payoff is low compared to alternatives[42]. This predicts that subjects will disengage from high-degree redirection tasks when the energetic cost outweighs the perceived *Hormē*-value.
- **Resource-depletion effects:** While debated, evidence suggests that acts of self-control can deplete glucose levels, leading to subsequent failures in executive function[43]. Under the scalar framework, we predict a specific **top-down collapse**: subjects in a state of depletion should show **preserved reflexive/reactive responses** (Degree 2) but **impaired deliberative/reflective planning** (Degrees 4–5).

Operationally, this means:

- Degree 2 (reflexive): Startle responses, withdrawal from pain
- Degree 3 (emotional): Simple approach/avoidance, conditioned responses
- Degree 4 (deliberative): Novel problem-solving, multi-step planning
- Degree 5 (reflective): Moral reasoning, self-monitoring accuracy

7.3 Prediction 3: The Pathology of Mis-directed *Hormē*

If mental illness and behavioral pathology often represent **disorders of causal redirection**, then specific syndromes should map onto predictable failures within the scalar stack.

7.3.1 Specific Tests:

- **Addiction:** Should manifest as a **hijacking of redirection mechanisms**—short-term reward-seeking overriding long-term persistence goals. Neurologically, this should correlate

[41] See Marcus E. Raichle, "Two Views of Brain Function," *Trends in Cognitive Sciences* 14, no. 4 (2010): 180–90.

[42] See Robert Kurzban et al., "An Opportunity Cost Model of Subjective Effort," *Behavioral and Brain Sciences* 36, no. 6 (2013): 661–79.

[43] See Matthew T. Gailliot et al., "Self-Control Relies on Glucose as a Limited Energy Source: Willpower Is More Than a Metaphor," *Journal of Personality and Social Psychology* 92, no. 2 (2007): 325–36.

with overpowering of prefrontal (reflective) regulation by subcortical (emotional/reactive) drives[44].

- **Depression:** Should involve a **global reduction in perceived causal efficacy**—a diminished sense that one's actions can redirect future states. This should be measurable as reduced initiation of goal-directed behavior and altered energy-allocation patterns in the brain's motivation circuits.
- **Impulse-control disorders:** Should reflect **failures at specific degrees of freedom** (e.g., reactive dominance over deliberative inhibition) with corresponding neural signatures (e.g., amygdala-prefrontal dysregulation).
- **Recovery prediction:** Therapeutic interventions should show degree-specific response patterns. Restoring Degree 2-3 function (stabilizing sleep, basic routines) should precede recovery of Degree 4-5 capacities (planning, self-reflection). Attempting to engage Degree 5 processes (CBT, moral reasoning) before stabilizing lower degrees should show poor efficacy.

7.4 Prediction 4: The Non-Agency of Current Artificial Systems

If genuine agency requires **internally-regulated *Hormē***—a self-maintaining far-from-equilibrium organization—then current artificial intelligence and robotics systems, which lack this constitutive drive, should **simulate but not instantiate** free will.

7.4.1 Specific Tests:

- **Goal-stability:** A truly agentic system should **resist external goal-substitution** if that substitution threatens its persistence. Current AI systems can be arbitrarily reprogrammed with new objectives without internal resistance—they lack *Hormē*.
- **Energy-autonomy:** Systems that cannot harvest and allocate their own energy to maintain their organizational boundaries are **thermodynamically parasitic**, not agentic. A robot that stops when unplugged fails the basic test of self-maintenance.
- **Pathological vs. adaptive failure:** A living agent, when failing, tends toward dissolution. An AI, when failing, tends toward nonsense or halt—it does not "strive" to recover in a goal-directed manner unless specifically programmed to do so.

7.5 Prediction 5: The Developmental Trajectory of Freedom

If free will scales with cognitive and physiological complexity, then the **ontogeny of agency** in humans should recapitulate—in compressed form—the phylogenetic scalar stack.

[44]See Nora D. Volkow et al., "Neurobiology of Addiction: A Neurocircuitry Analysis," *The Lancet Psychiatry* 3, no. 8 (2016): 760–73.

7.5.1 Specific Tests:

- **Infants:** Should exhibit primarily reactive and emotional agency (Degrees 2–3), with deliberative capacity emerging alongside prefrontal cortex maturation.
- **Adolescents:** Should show increased capacity for deliberative agency (Degree 4) but with notable failures under high arousal, reflecting ongoing integration of limbic and cortical systems.
- **Adults:** Should achieve stable reflective agency (Degree 5) in those with developed metacognitive and normative faculties. Impairments in these faculties (e.g., in certain neurodevelopmental or psychiatric conditions) should correspond to measurable deficits in higher-degree causal redirection.

7.6 Prediction 6: The Evolutionary Continuity of Agency

If each degree of freedom builds upon earlier ones through evolutionary descent, then we should find **neuro-biological and behavioral homologues** across the scalar stack.

7.6.1 Specific Tests:

- **Genetic and neural homology:** The genetic toolkit and neural circuit motifs underlying bacterial chemotaxis (e.g., two-component signaling systems) should find analogues in more complex nervous systems (e.g., G-protein-coupled receptor cascades in neuromodulation)[45].
- **Behavioral gradients:** There should be no sharp "agency threshold" in phylogeny. Instead, we should observe smooth gradients in behavioral flexibility, planning depth, and self-regulation across related clades (e.g., along the primate lineage).

7.7 Why These Predictions Matter

These are not mere technical hypotheses. They operationalize the central claim of this paper: **free will is a natural, scalable, and thermodynamically grounded phenomenon**. If confirmed, they would:

1. **Naturalize freedom entirely**, removing it from the realm of metaphysical speculation.
2. **Provide a unified framework** for psychology, neuroscience, and biology—treating agency as a continuous variable rather than a human exception.
3. **Offer clear criteria** for assessing claims of artificial agency—preventing the premature attribution of freedom to sophisticated but *Hormē*-less machines.
4. **Guide therapeutic interventions** by targeting specific degrees of agentive failure in psychopathology.

[45] See Judith P. Armitage, "Bacterial Tactic Responses," *Advances in Microbial Physiology* 41 (1999): 229–89.

The framework is thus not only philosophically satisfying but **scientifically fertile**. It invites collaboration across disciplines to map the architecture of freedom—from its thermodynamic foundations to its highest human expressions.

8 Implications: Rethinking Responsibility, Machines, and Moral Practice

A theory that merely explains is of academic interest; a theory that transforms practice is of philosophical importance. The scalar, thermodynamic account of free will does not only resolve a centuries-old debate—it reshapes how we think about moral responsibility, artificial intelligence, mental health, education, and even our place in the natural world. This section explores those practical implications.

8.1 Moral Responsibility: From Metaphysical Blame to Navigational Accountability

The traditional link between free will and moral responsibility is straightforward: if you could not have done otherwise, you cannot be blamed. This "control condition" has fueled endless debates about determinism, luck, and exemption. The scalar framework offers a different foundation: **responsibility tracks navigational competence**.

8.1.1 The Navigational Account of Responsibility

Under this view, to hold someone responsible is to evaluate **how well they directed causal flow given their models and capacities**. This shifts the focus from **metaphysical freedom** to **practical efficacy**. Consider two drivers who run red lights:

- **Driver A:** Distracted by a medical emergency in the passenger seat.
- **Driver B:** Texting for amusement.

Both performed the same physical action with the same outcome (running the light). Traditional frameworks struggle to distinguish their blameworthiness if both actions were "determined." The navigational account distinguishes them clearly:

- **Driver A's** redirection capacity was overwhelmed by a competing *Hormē* (saving a life). Their failure occurred under extreme constraint.
- **Driver B's** redirection capacity was voluntarily diverted toward trivial gratification. Their failure reflects poor navigational discipline.

8.1.2 Degrees of Responsibility

Just as freedom is scalar, so too is responsibility. We can construct a **responsibility gradient** that corresponds to the degrees of freedom:

- **Degree 0–1 (Bacteria/Plants):** No responsibility—action is direct expression of *Hormē* without model-based alternatives.
- **Degree 2–3 (Insects/Mammals):** Limited responsibility—accountable for learned behaviors but not for reflective norm-governance.
- **Degree 4–5 (Primates/Humans):** Full responsibility—capable of modeling consequences, weighing values, and choosing accordingly.

This approach **dissolves the problem of moral luck**. We judge the **quality of the navigation**, not the contingent outcomes. The reckless driver who luckily hits no one is as blameworthy as the one who hits a pedestrian—their navigational failure is identical. The outcome is relevant for **consequential repair** (compensation, deterrence) but not for **agential assessment**.

8.2 Artificial Intelligence: The *Hormē* Threshold

The "alignment problem" in AI ethics asks how to ensure artificial systems act in accordance with human values.[46] The scalar framework reveals that this problem is fundamentally mis-stated for current AI: **without *Hormē*, there is no "who" to align.**

8.2.1 Current AI: Sophisticated Tools, Not Agents

Today's large language models and robotics systems exhibit **behavioral sophistication without agential grounding**. They simulate conversation, generate plausible text, and even emulate reasoning—but they lack:

1. **A bounded organization to maintain** (no self-interest).
2. **Internally-regulated energy expenditure** to sustain that organization.
3. **The constitutive drive to redirect causal flow toward persistence.**

Therefore, they have **Degree 0 freedom**—none. They are **navigational instruments**, not navigators. The ethical challenge is not "aligning their values" but **designing them to enhance human navigation without introducing uncontrolled causal redirection**. The ultimate responsibility for the actions of AI systems therefore lies solely with the companies and programmers implementing them[47].

8.2.2 Future AGI: The *Hormē* Criterion

If we someday create systems with genuine *Hormē*—self-maintaining far-from-equilibrium organizations that harvest and allocate energy to persist—they would possess minimal agency (Degree 1+). At that point, the alignment problem becomes real: how do we ensure their *Hormē* is

[46] See Nick Bostrom, *Superintelligence: Paths, Dangers, Strategies* (Oxford University Press, 2014).

[47] See Joanna J. Bryson, "Robots Should Be Slaves," in *Close Engagements with Artificial Companions: Key Social, Psychological, Ethical and Design Issues*, ed. Yorick Wilks (John Benjamins, 2010) for the definitive argument that AI systems must remain legal property ("slaves") to ensure that liability remains firmly with their human creators.

compatible with ours? The scalar framework suggests **co-navigation** rather than **master-slave** dynamics: designing systems whose persistence is symbiotically tied to human flourishing.

8.3 Mental Health: Disorders of Navigation

Psychopathology has long been described in terms of dysfunction, distress, and deviation. The navigational framework offers a unifying lens: **mental illness as a disruption in the capacity to redirect causal flow effectively toward *Hormē*-fulfillment.**

8.3.1 A Navigational Taxonomy of Pathology

- **Anxiety disorders:** Excessive prediction of threat → hyper-vigilant but inefficient redirection (energy wasted on avoidance).
- **Depression:** Diminished belief in causal efficacy → reduced initiation of redirection (energetic withdrawal).
- **Addiction:** Hijacking of redirection mechanisms toward short-term reward at the expense of long-term persistence.
- **Psychosis:** Severe breakdown in model-reality alignment → redirection based on faulty maps.

Treatment, under this view, becomes **navigational retraining**: restoring accurate modeling, recalibrating energy allocation, and rebuilding confidence in one's causal efficacy. This aligns with modern modalities like Cognitive Behavioral Therapy (refining models)[48] and behavioral activation (restoring redirection practice) but grounds them in a deeper theory of what agency is.

8.4 Education: Cultivating Navigators, Not Repositories

Modern education often fractures into "STEM" (facts, skills) and "humanities" (values, interpretation). The scalar framework suggests a unified purpose: **developing competent navigators**.

8.4.1 An Integrated Curriculum

- **Science:** Teaches map-making—how to model the *Logos* accurately.
- **Ethics:** Teaches way-finding—how to direct causal flow toward flourishing.
- **Literature & History:** Provide simulated navigational experiences—exploring how others have navigated complex terrain.
- **Meta-cognitive training:** Teaching students to monitor and regulate their own navigational processes—the *Logistikon* at work.

[48] See Judith S. Beck, *Cognitive Behavior Therapy: Basics and Beyond*, 3rd ed. (The Guilford Press, 2020) for the definitive account of the cognitive model and restructuring techniques.

The goal is not merely knowledgeable graduates but **capable agents** who can redirect causal flow wisely across personal, professional, and civic domains. This recovers the classical ideal of *paideia*—education as character-formation—but with a naturalistic, navigational core.

8.5 Environmental Ethics: Recognizing Non-Human Agency

The scalar framework expands the moral circle not by granting "rights" to non-humans but by **recognizing their agency**. A tree foraging for light, a wolf pack hunting, a coral reef building its structure—each is engaged in *Hormē*-driven causal redirection.

8.5.1 Implications for Conservation and Stewardship

- **Respect for agency:** Interventions should minimize unnecessary frustration of other beings' *Hormē*.
- **Ecological navigation:** Ecosystems are networks of co-navigating agents. Sustainability is the art of maintaining navigational possibility for all.
- **Beyond anthropocentrism:** Value is not solely human-centered; it resides in the **fulfillment of *Hormē*** wherever it occurs.

This does not mean trees have "rights" equal to humans (they operate at Degree 1, not Degree 5), but it does mean their striving deserves **consideration in our moral calculus**, especially when our actions permanently extinguish it.

8.6 Conclusion: A World Full of Agents

The scalar theory of free will does more than solve a philosophical puzzle. It **re-enchants the natural world** with agency—not by supernatural addition but by scientific recognition. From the bacterium swimming upstream to the poet wrestling with a line, the universe is teeming with beings **striving to shape their futures**.

The practical task ahead is not to prove we are free, but to **become better at freedom**—to refine our models, direct our energy wisely, and navigate toward futures worth having. The theory provides the map; the practice is up to us.

9 Objections & Replies

No philosophical thesis is complete without confronting its strongest critics. The scalar, thermodynamic account of free will presented here challenges deeply held intuitions and academic orthodoxies. This section addresses the most significant objections, demonstrating not only the framework's resilience but its explanatory superiority.

9.1 Objection 1: "This Isn't 'Real' Free Will!"

The Objection: "You've changed the subject. When people talk about free will, they mean the ability to make choices that are *truly* up to them—uncaused, undetermined, and ultimately responsible. What you're describing is just goal-directed behavior. Calling that 'free will' is a semantic sleight of hand."

Reply: This objection assumes there is a settled, coherent pre-theoretical meaning of "free will" that the theory must capture. But the history of the debate shows precisely the opposite: **there is no consensus on what 'real' free will is**. Libertarians, compatibilists, and hard determinists all mean different things by the term.

The scalar framework does not change the subject; it **clarifies the referent**. What people *experience* as free will—the feeling of effort, choice, and causal efficacy—is exactly the somatic and psychological signature of redirecting causal flow. What they *theorize* about free will—uncaused causation—is a metaphysical gloss on that experience. The theory explains the experience without invoking the incoherent gloss.

Moreover, this objection commits the **human-exceptionalist fallacy**. It assumes that whatever freedom is, it must be unique to humans. But if we discover that the same basic capacity for causal redirection exists across life, **the burden shifts** to the objector to explain why the human version is "real" while the bacterial version is not. The scalar account provides a continuous, naturalistic explanation; the traditional view must posit a mysterious discontinuity.

9.2 Objection 2: "But Determinism!"

The Objection: "If the universe is deterministic, then everything that happens, including every 'choice,' is fixed by prior states. Your notion of 'redirecting causal flow' is just a deterministic process playing out. Nothing is genuinely redirected—it was always going to happen that way."

Reply: This objection fails because **hard determinism is not an established fact—it is an unprovable metaphysical claim** that contradicts the observable evidence of biological agency.

Hard determinism assumes the causal flow of the universe is **closed to intervention**—that living systems are merely carried along a pre-set trajectory. But this is **facts not in evidence**. While the ultimate origin of life and its constitutive *Hormē* remains a scientific mystery, the **operation** of this capacity is observable reality. The life-agency isomorphism (T6) demonstrates that to be alive *just is* to possess the capacity to redirect causal flow[49].

A bacterium swimming up a gradient is not an illusion of redirection; it is **physical, measurable intervention** in the diffusion-driven flow of particles. Its action changes what happens

[49] See Eli Adam Deutscher, *Life as Directed Causality: A Thermodynamic Isomorphism Between Being and Acting*, 2025, 7–9.

next in a way that would not happen if it were dead. This is not philosophy—it is **empirical thermodynamics**.

Thus, **the burden of proof is reversed**. It is not on me to prove that agency exists within determinism; it is on the hard determinist to prove that the observable, thermodynamic work of living systems **does not actually redirect causal flow**. They must demonstrate that metabolism, locomotion, and homeostasis are causally inert—that a living cell and a dead one have identical effects on future states.

The hard determinist must explain why natural selection favored organisms that can navigate chemical gradients if that navigation has no causal effect on survival outcomes. This position is not just anti-thermodynamics—it is anti-Darwinian.

The life-agency isomorphism is **validated** in the sense that it explains the data of biology and behavior better than any alternative. By the logic of the **Confidence Gradient (C2)**—where knowledge is measured by predictive reliability rather than absolute certainty—this is the proper way to navigate[50]. Hard determinism, by contrast, is a **low-confidence model** that asks us to disregard the high-confidence evidence of our own causal efficacy in favor of an untestable speculation about the universe's ultimate causal structure.

In short: **Life *is* interference in the mechanistic flow of time.** To deny that is to deny that life exists—to claim we are nothing more than fancy rocks.

9.3 Objection 3: "Consciousness is Essential!"

The Objection: "Free will requires consciousness. A bacterium isn't conscious, so it can't be free. Your account ignores the first-person experience of choice—the 'what it's like' to decide."

Reply: This objection conflates **free will with conscious free will**. The scalar framework distinguishes:

- **Minimal free will (Degrees 0–2):** Causal redirection without consciousness.
- **Conscious free will (Degrees 3–5):** Causal redirection accompanied by and modulated by conscious experience.

Consciousness is not the *source* of agency but its **amplifier and integrator**. It allows for more complex modeling, long-range planning, and value-based reflection. But the engine of agency—*Hormē*—runs deeper. Just as a self-driving car can navigate without a passenger, a living system can redirect causal flow without consciousness.

Importantly, the **hard problem of consciousness** remains untouched by this theory. But the "hard problem of free will" dissolves once we see that the core capacity does not depend on

[50] See Deutscher, *Neo-Pre-Platonic Naturalism*, 225.

consciousness. We can study the evolution and mechanisms of agency without first solving consciousness—just as we can study flight without first solving qualia.[51]

9.4 Objection 4: "This is Just Compatibilism in Disguise."

The Objection: "You're saying free will is compatible with determinism and that it's about acting according to one's desires/goals. That's exactly what compatibilists say. You've just added Greek terms and thermodynamics."

Reply: While there are surface similarities, the scalar framework differs from standard compatibilism in three crucial ways:

1. **Scalarity vs. Binary:** Compatibilism typically treats free will as a yes-no property of certain human actions. The scalar account presents it as a continuum across life.
2. **Hormē* vs. Desires:** Compatibilists ground freedom in "desires" or "volitions," which are taken as psychological givens. The scalar account traces desires to *Hormē*—a constitutive, biological drive—explaining where desires come from and why they have normative force.
3. **Thermodynamic Grounding:** Compatibilism is often purely conceptual or psychological. The scalar account provides a **physical basis** in energy expenditure and far-from-equilibrium dynamics.

In short, compatibilism is a **philosophical reconciliation**; the scalar account is a **scientific explanation**. One tries to make freedom fit into a deterministic world; the other shows how freedom emerges from that world's physics.

9.5 Objection 5: "What About Moral Responsibility?"

The Objection: "If a bacterium has minimal free will, does that make it morally responsible? If not, how do you draw the line? Your scalar approach seems to blur the boundary between responsible and non-responsible agents."

Reply: Responsibility is indeed scalar and tracks **degrees of freedom**, specifically the capacity for **reflective norm-governance** (Degree 5). The line is not arbitrary; it follows from the capacities required to be accountable to moral norms:

- **To be morally responsible**, an agent must be able to:

1. Model the consequences of actions for others' *Hormē*.
2. Understand and apply normative principles.
3. Reflectively endorse or reject motives.

[51] For the formal NPN rebuttal to the "Hard Problem" of consciousness as a category error, see Deutscher, *Neo-Pre-Platonic Naturalism*, Appendix J.3.1. For the technical derivation of the life-mind continuity that dissolves this gap through thermodynamic isomorphism, see Deutscher, *Life as Directed Causality*, §5 ("Dissolving the Life/Mind Gap").

- These capacities emerge only at the highest degrees of freedom (primates, cetaceans, humans).

Thus, a bacterium is **not morally responsible**—not because it lacks "real" free will, but because it lacks the cognitive machinery for moral consideration. The scalar stack provides a **principled basis** for responsibility gradients in law, ethics, and everyday judgment.

9.6 Objection 6: "The Evidence is Still Compatible with Illusionism."

The Objection: "Even if your account is coherent, the hard determinist/illusionist can still argue that the feeling of effort and choice is a post-hoc confabulation. Neuroscience (e.g., Libet-style experiments) shows neural preparation before conscious intention. Maybe all 'redirection' is just deterministic brain activity we narrate as choice."

Reply: This objection misinterprets the neuroscience and commits a **mereological fallacy**. The fact that neural processes precede conscious awareness does not prove that those processes are not **agentive**. It only shows that consciousness is not the first link in the causal chain—which the scalar account already acknowledges (agency precedes consciousness). Furthermore, philosophers have forcefully argued that consciousness is required for the specific type of control needed for *moral* responsibility, distinguishing "zombie" agency from the kind we care about in the free will debate[52].

More importantly, illusionism cannot explain **why the feeling of effort correlates with metabolic cost**, why **energy depletion impairs decision-making**, or why **animals without sophisticated narrative capacity still exhibit goal-directed behavior**. The illusionist must treat these as colossal coincidences. The scalar account explains them as **direct manifestations of the thermodynamic work of agency**.

Finally, illusionism faces a **performative contradiction**: it uses conscious, reasoned argument to try to convince us that conscious reason is causally impotent. The scalar account avoids this by placing reason within the toolkit of an agent engaged in navigating reality—reason is one of our most powerful redirection tools.

9.7 Objection 7: "You've Ignored Quantum Indeterminacy."

The Objection: "Modern physics suggests the universe is not deterministic but probabilistic at the quantum level. Doesn't this open the door for libertarian free will after all?"

Reply: Quantum indeterminacy does not rescue libertarianism; it is largely **irrelevant to agency**. Randomness is not freedom. If my choices were the result of quantum noise, they would

[52] See Joshua Shepherd, "Consciousness, Free Will, and Moral Responsibility," *Philosophical Psychology* 28, no. 7 (2015): 929–46 for an analysis of consciousness, free will, and moral responsibility.

be **uncontrolled**, not **self-controlled**. Libertarianism needs *non-random, uncaused* causation—which is not provided by quantum mechanics.

More importantly, the scalar account does not depend on whether the baseline physics is deterministic or indeterministic. Agency works **within whatever causal structure exists** by expending energy to bias probabilities. In a deterministic world, it biases trajectories. In an indeterministic world, it biases probability distributions. The core mechanism—**work to redirect flow**—is unchanged.

9.8 Conclusion: A Framework That Withstands Scrutiny

These objections, while serious, ultimately strengthen the scalar account. They force clarification, reveal hidden assumptions in traditional views, and demonstrate the theory's explanatory breadth. The framework does not simply avoid problems; it **transforms them** into empirical questions about navigation, energy, and complexity.

The ultimate test is not whether the theory matches every pre-theoretic intuition—many of those intuitions are contradictory—but whether it provides a **coherent, empirically grounded, and practically useful** understanding of what it means to be an agent in a lawful world. By that measure, the scalar account succeeds where the traditional debate has stalled.

10 Conclusion: Freedom as Life's Work

We began with a stalemate—a centuries-old debate trapped between unsatisfying alternatives: ghostly libertarian freedom, hollow compatibilist accommodation, or nihilistic hard determinism. Each position shared a fatal flaw: they sought to understand free will by looking only at its most complex, recent, and conscious human manifestation, while ignoring its biological roots. By shifting our gaze downward to the simplest living systems, we have discovered that freedom is not a metaphysical anomaly but a **natural phenomenon with a billion-year history**.

10.1 The Scalar Revelation

The central insight of this paper is that **free will is scalar, not binary**. It is not a light switch that turns on only in human minds but a **continuum of causal-redirection capacity** that deepens with evolutionary complexity:

- **Degree 0:** The bacterium swimming up a gradient.
- **Degree 1:** The tree root foraging around a rock.
- **Degree 2:** The fly dodging a swatter.
- **Degree 3:** The dog choosing between safety and curiosity.
- **Degree 4:** The chimpanzee planning a deception.

- **Degree 5:** The human living by principle.

At every level, the same two components are present: ***Hormē***, the constitutive drive to persist, and the **expenditure of energy to redirect causal flow** toward that end. What changes is not the essence of agency but its **tools**: from direct sensor-effector coupling to emotional valuation to abstract modeling and normative self-governance.

10.2 Why the Stalemate Dissolves

The traditional debate asked: "Can we be uncaused causers in a causally closed world?" This question presupposed that freedom must be an **exception to physics**. The scalar account shows that freedom is instead a **consequence of a particular kind of physics**—the physics of far-from-equilibrium, self-maintaining systems. We are not exceptions to the causal order; we are **elaborations of it**.

- **Libertarianism** sought freedom *outside* nature and found only mystery.
- **Hard determinism** denied freedom *within* nature and found only illusion.
- **Compatibilism** redefined freedom to fit nature but lost its depth.

The scalar account **naturalizes freedom without reducing it**. It shows that our deepest experiences of choice, effort, and responsibility are not illusions but **somatic and psychological signatures of the thermodynamic work we do to navigate reality**. The feeling of freedom is real because the work is real.

10.3 A New Compass for Philosophy and Science

This re-framing does more than solve an old puzzle; it provides a **new compass** for inquiry across disciplines:

- **For neuroscience and psychology:** Study agency as a scalable capacity for causal redirection, linking metabolic cost to behavioral complexity.
- **For ethics and law:** Ground responsibility in navigational competence rather than metaphysical freedom.
- **For artificial intelligence:** Distinguish genuine agency (requiring *Hormē*) from sophisticated simulation.
- **For education:** Cultivate navigators who can model reality accurately and direct causal flow wisely.
- **For environmental ethics:** Recognize the striving of all living systems as worthy of consideration.

The framework is **empirically accountable**, making testable predictions about energy, behavior, and development. It invites collaboration rather than compartmentalization.

10.4 Final Reflection: What We Are

We have spent millennia wondering if we are free, as if freedom were a possession we might lack. The scalar account suggests a more fundamental truth: **freedom is not something we have; it is something we are**. To be alive is to be a bounded organization engaged in the work of persistence—to be a navigator in a world that tends toward equilibrium.

From this perspective, the question is not "Are we free?" but **"How are we free, and what shall we do with that freedom?"** The bacterium answers by swimming. The human answers by choosing, building, loving, creating, and sometimes sacrificing—redirecting causal flow across expanding horizons of space, time, and meaning.

The debate over free will ends not with a definitive "yes" or "no" but with a recognition: we are participants in a ancient, continuous, and awe-making project—the project of life striving to shape its future. Our freedom is not a break in the causal chain; it is **our link in the chain**. And with that link, we are tasked not only with persisting but with persisting *well*—with navigating toward futures worth having, for ourselves and for the other navigators with whom we share this world.

We are the universe's way of choosing itself—not through metaphysical exemption, but through thermodynamic work. Let us choose wisely.

---

*This paper is part of the larger systematic inquiry developed in *Neo-Pre-Platonic Naturalism (2025)*, which derives these core concepts from the fundamental logic of distinction.

References

Adler, Julius. "Chemotaxis in Bacteria." *Science* 153, no. 3737 (1966): 708–16.

Aristotle. *Nicomachean Ethics*. Translated by T. Irwin. Hackett Publishing, 1999.

Armitage, Judith P. "Bacterial Tactic Responses." *Advances in Microbial Physiology* 41 (1999): 229–89.

Augustine. *The City of God Against the Pagans*. Translated by R. W. Dyson. Cambridge University Press, 1998.

Beck, Judith S. *Cognitive Behavior Therapy: Basics and Beyond*. 3rd ed. The Guilford Press, 2020.

Berg, Howard C., and Douglas A. Brown. "Chemotaxis in *Escherichia Coli* Analysed by Three-Dimensional Tracking." *Nature* 239, no. 5374 (1972): 500–504.

Bostrom, Nick. *Superintelligence: Paths, Dangers, Strategies*. Oxford University Press, 2014.

Bryson, Joanna J. "Robots Should Be Slaves." In *Close Engagements with Artificial Companions: Key Social, Psychological, Ethical and Design Issues*, edited by Yorick Wilks. John Benjamins, 2010.

Call, Josep, and Michael Tomasello. *Primate Cognitive Systems*. Oxford University Press, 2010.

Carew, Thomas J., and Christie L. Sahley. "Invertebrate Learning and Memory: From Behavior to Molecules." *Annual Review of Neuroscience* 9, no. 1 (1986): 435–87.

Carruthers, Peter. "How We Know Our Own Minds: The Relationship Between Mindreading and Metacognition." *Behavioral and Brain Sciences* 32, no. 2 (2009): 121–38.

Chisholm, Roderick M. "Human Freedom and the Self." *The Lindley Lecture*, University of Kansas, 1964, 3–15.

Clayton, Nicola S., Joanna M. Dally, and Nathan J. Emery. "Social Cognition by Food-Caching Corvids. The Western Scrub-Jay as a Natural Psychologist." *Philosophical Transactions of the Royal Society B: Biological Sciences* 362, no. 1480 (2007): 507–22.

Darwin, Charles. *The Power of Movement in Plants*. John Murray, 1880.

Daura-Jorge, F. G., M. Cantor, S. N. Ingram, D. Lusseau, and P. C. Simões-Lopes. "The Structure of a Bottlenose Dolphin Society Is Coupled to a Unique Foraging Cooperation with Artisanal Fishermen." *Biology Letters* 8, no. 5 (2012): 702–5. https://doi.org/10.1098/rsbl.2012.0174.

Dennett, Daniel C. *Freedom Evolves*. Viking, 2003.

Descartes, René. *Meditations on First Philosophy*. Translated by J. Cottingham. Cambridge University Press, 1986.

Deutscher, Eli Adam. *Life as Directed Causality: A Thermodynamic Isomorphism Between Being and Acting*. 2025.

Deutscher, Eli Adam. *Neo-Pre-Platonic Naturalism*. Neo-Pre-Platonic Press, 2025.

Frankfurt, Harry G. "Freedom of the Will and the Concept of a Person." *The Journal of Philosophy* 68, no. 1 (1971): 5–20.

Gailliot, Matthew T., Roy F. Baumeister, C. Nathan DeWall, et al. "Self-Control Relies on Glucose as a Limited Energy Source: Willpower Is More Than a Metaphor." *Journal of Personality and Social Psychology* 92, no. 2 (2007): 325–36.

Hodge, Angela. "Root Decisions." *Plant, Cell & Environment* 32, no. 6 (2009): 628–40.

Hume, David. *An Enquiry Concerning Human Understanding*. Edited by T. L. Beauchamp. Oxford University Press, 2000.

Kant, Immanuel. *Critique of Pure Reason*. Translated by P. Guyer and A. W. Wood. Cambridge University Press, 1998.

Karban, Richard. "Plant Behaviour and Communication." *Ecology Letters* 11, no. 7 (2008): 727–39.

Karg, Katja, Martin Schmelz, Josep Call, and Michael Tomasello. "Chimpanzees Strategically Manipulate What Others Can See." *Animal Cognition* 18 (2015): 1069–76. https://doi.org/10.1007/s10071-015-0875-z.

Kauffman, Stuart A. *The Origins of Order: Self-Organization and Selection in Evolution.* Oxford University Press, 1993.

Kurzban, Robert, Angela Duckworth, Joseph W. Kable, and Justus Myers. "An Opportunity Cost Model of Subjective Effort." *Behavioral and Brain Sciences* 36, no. 6 (2013): 661–79.

LeDoux, Joseph. "Rethinking the Emotional Brain." *Neuron* 73, no. 4 (2012): 653–76.

Libet, Benjamin. "Unconscious Cerebral Initiative and the Role of Conscious Will in Voluntary Action." *Behavioral and Brain Sciences* 8, no. 4 (1985): 529–39.

McGrew, W. C. "Is Primate Tool Use Special? Chimpanzee and New Caledonian Crow Compared." *Philosophical Transactions of the Royal Society B: Biological Sciences* 368, no. 1630 (2013): 20120422. https://doi.org/10.1098/rstb.2012.0422.

Metcalfe, Janet, and Arthur P. Shimamura, eds. *Metacognition: Knowing about Knowing.* MIT Press, 1994.

Morowitz, Harold J. *Energy Flow in Biology.* Academic Press, 1968.

Nicholls, David G., and Stuart J. Ferguson. *Bioenergetics.* 4th ed. Academic Press, 2013.

Nicolis, G., and I. Prigogine. *Self-Organization in Nonequilibrium Systems.* Wiley, 1977.

Osvath, Mathias. "Spontaneous Planning for Future Stone Throwing by a Male Chimpanzee." *Current Biology* 19, no. 5 (2009): R190–91. https://doi.org/10.1016/j.cub.2009.01.010.

Panksepp, Jaak. *Affective Neuroscience: The Foundations of Human and Animal Emotions.* Oxford University Press, 1998.

Raichle, Marcus E. "Two Views of Brain Function." *Trends in Cognitive Sciences* 14, no. 4 (2010): 180–90.

Schrödinger, Erwin. *What Is Life? The Physical Aspect of the Living Cell.* Cambridge University Press, 1944.

Shepherd, Joshua. "Consciousness, Free Will, and Moral Responsibility." *Philosophical Psychology* 28, no. 7 (2015): 929–46.

Simard, Suzanne W., David A. Perry, Melanie D. Jones, David D. Myrold, Daniel M. Durall, and Randy Molina. "Net Transfer of Carbon Between Ectomycorrhizal Tree Species in the Field." *Nature* 388, no. 6642 (1997): 579–82.

Suddendorf, Thomas, and Michael C. Corballis. "The Evolution of Foresight: What Is Mental Time Travel, and Is It Unique to Humans?" *Behavioral and Brain Sciences* 30, no. 3 (2007): 299–313.

Tan, Ken, Weiwen Chen, Shihao Dong, Xiwen Liu, Yuchong Wang, and James C. Nieh. "Imidacloprid Alters Foraging and Decreases Bee Avoidance of Predators." *PLoS ONE* 9, no. 7 (2014): e102725. https://doi.org/10.1371/journal.pone.0102725.

Trewavas, Anthony. "Aspects of Plant Intelligence." *Annals of Botany* 92, no. 1 (2003): 1–20.

Tully, Tim, Thomas Preat, S. C. Boynton, and M. Del Vecchio. "Gene Disruption of Learning and Memory: A Structure-Function Perspective." *Cell* 79, no. 1 (1994): 35–47.

Volkow, Nora D., George F. Koob, and A. Thomas McLellan. "Neurobiology of Addiction: A Neurocircuitry Analysis." *The Lancet Psychiatry* 3, no. 8 (2016): 760–73.

Wadhams, George H., and Judith P. Armitage. "Making Sense of It All: Bacterial Chemotaxis." *Nature Reviews Microbiology* 2, no. 12 (2004): 1024–37.

Wegner, Daniel M. *The Illusion of Conscious Will.* MIT Press, 2002.