The Grammar of Iteration

Hasok Chang's Epistemic Iteration and the Closure Framework: How Scientific Knowledge Improves Itself from Imperfect Starting Points

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> *We start from something quite uncertain. But you take that as your provisional standard, which allows you to go and make investigations. Then, having made such investigations, hopefully you learn something that allows you to come back to your starting point and correct or refine it. That is epistemic iteration.*
> Hasok Chang, HPS Podcast, 2023

> *Every finite closure generates remainder. The remainder is not noise. It is the proof that the grammar is finite.*
> CF Dietz, Consciousness, Closure, and the Cosmos, 2026

Abstract

Hasok Chang is Professor of History and Philosophy of Science at the University of Cambridge and one of the most important contemporary philosophers of science working at the intersection of history and philosophy of science. His three major contributions to philosophy of science are epistemic iteration, the account of how scientific knowledge improves itself by using the outcomes of inquiry to correct the provisional standards from which the inquiry began; operational coherence, his pragmatist account of truth as the coherent functioning of systems of epistemic activity rather than correspondence to mind-independent reality; and activist realism, his commitment to do everything possible to improve knowledge of realities, treating reality as what inquiry is directed at learning from rather than as an ultimate structure our theories must correspond to. This paper argues that Chang's framework and the closure framework developed in Consciousness, Closure, and the Cosmos converge at a philosophically precise point: epistemic iteration is supersession in the history of science. Every closure used to conduct inquiry generates remainder, the anomalies, the failures of prediction, the phenomena the current framework cannot accommodate. That remainder is the input for the next iteration: the new provisional standard that is itself imperfect but less imperfect than the previous one, used to conduct further inquiry that will generate further remainder for the next iteration. Operational coherence is what any closure achieves when it constitutes its facts successfully: the smooth functioning of the system of epistemic activities organized around those facts, maintained against the remainder that would dissolve it. And activist realism is the stance of a knower who acknowledges that every closure generates remainder and commits to using that remainder to improve the closure rather than defending the current constitution against the pressure of what the closure cannot absorb. Together, Chang's three concepts constitute the epistemological account of what the closure framework describes structurally: knowledge as the ongoing improvement of finite closures through the pressure of their own remainder.

1. The Thermometer That Measured Itself

How do you calibrate a thermometer? You need to know the temperature at two fixed points to set the scale. The standard method uses the freezing point and boiling point of water: zero degrees and one hundred degrees Celsius. But wait. How do you know that water boils at a fixed temperature? You measure it with a thermometer. And how do you know the thermometer is accurate? It was calibrated using the boiling point of water.

This is not a mere circular curiosity. It is the logical structure of a fundamental problem in the history of measurement that Hasok Chang explored in Inventing Temperature. The early thermoscopists faced exactly this difficulty: they had instruments that responded to heat, but they had no way of verifying that those instruments were accurate that did not already presuppose some standard of heat measurement. The validation of the measuring instrument required the measured phenomenon, and the measured phenomenon required the measuring instrument. There was no external Archimedean point from which the whole system could be verified independently.

Chang's response to this difficulty is epistemic iteration. You do not need an Archimedean point. You start from where you stand, with an imperfect thermoscope and provisional assumptions about what counts as a fixed thermal point. You use that imperfect starting position to conduct inquiries into thermal phenomena. The inquiries reveal things that do not fit the provisional assumptions: the boiling point of water turns out to vary with pressure, certain liquids have different thermal expansion profiles than others, some substances exhibit anomalous behavior near phase transitions. These findings are the remainder of the provisional closure: what the current framework cannot absorb. You use that remainder to return to the starting point and revise it. The revised starting point is more accurate than the original one. You use it to conduct further inquiries, which reveal further remainder, which drive further revisions. The whole chain exhibits innovative progress within a continuous tradition, each iteration less imperfect than the last.

This is the grammar of scientific progress as Chang understands it. Not the Popperian picture of bold conjectures refuted by crucial experiments, not the Kuhnian picture of normal science disrupted by revolutionary paradigm shifts, but the slower and more persistent picture of iterative improvement: closures generating remainder, remainder driving revision, revision producing better closures, those closures generating new remainder. The foundation is never certain. The foundation is always provisional. The goal is not to reach the certain foundation but to keep iterating toward it from wherever we currently stand.

2. Chang's Four Claims

Chang's contribution to history and philosophy of science has four interconnected components developed across three major books.

2.1 Epistemic Iteration: Progress Through Self-Correcting Circularity

Epistemic iteration is the process in which successive stages of knowledge, each building on the preceding one, are created in order to enhance the achievement of certain epistemic goals. The key structural feature is circularity that is not vicious: the later stage uses the earlier stage as its foundation while also correcting that foundation. The correction is made possible by the inquiries that the earlier stage enabled. The earlier stage was wrong in specific ways that only become visible once you use it to conduct the inquiries it makes possible.

Chang distinguishes epistemic iteration from simple trial-and-error. In trial-and-error, successive attempts are independent: each attempt starts fresh from the same problem. In epistemic iteration, successive stages are cumulative: each stage builds on the previous one and uses the outcomes of the inquiries it enables to return and improve the foundation from which it started. The whole chain is a developing tradition, not a series of independent experiments. Progress is real, measurable in the increasing operational coherence of each successive iteration, and continuous with what came before.

The thermometer case is the canonical example, but Chang develops the account across multiple historical cases: the calibration of thermometers, the development of acidity scales in chemistry, the refinement of temperature scales, the history of the concept of element through the Chemical Revolution. In each case, the same iterative structure appears: a provisional standard enables inquiry, the inquiry reveals the standard's limitations, the limitations drive revision of the standard, the revised standard enables better inquiry.

2.2 Systems of Practice: The Unit of Scientific Knowledge

Chang proposes that the basic unit of scientific knowledge is not the individual proposition or theory but the system of practice: an integrated set of epistemic activities organized around a shared framework of concepts, methods, and standards. A system of practice includes not only what scientists believe but what they do: how they design experiments, what they count as evidence, how they make measurements, what standards they apply in evaluating results, and what they consider to be a good explanation.

This move from propositions to practices is philosophically significant. It shifts the question of scientific knowledge from what propositions scientists believe and whether those beliefs are true to what activities scientists perform and whether those activities cohere operationally. Two systems of practice can produce different but both valid knowledge of the same domain if their epistemic activities cohere internally and both produce useful engagement with the world, even if their theoretical propositions are prima facie inconsistent. Scientific pluralism is a natural consequence of this framework: different systems of practice can illuminate different aspects of the same reality without any single system being the uniquely correct one.

2.3 Operational Coherence: Truth as Functional Integrity

Chang proposes operational coherence as the primary account of truth in empirical science, replacing correspondence to mind-independent reality. A system of epistemic activities achieves operational coherence when its components function together without breakdown: the concepts

used in the theory match the operations used to measure them, the predictions generated by the theory are confirmed by the experiments designed to test them, the standards used to evaluate evidence are consistent with the theoretical framework that specifies what to expect.

Operational coherence is achievable in actual scientific practice and improvable through epistemic iteration. It is not an ideal of perfect correspondence to ultimate reality but an operational standard that scientists can assess and improve as they conduct inquiry. When remainder accumulates, when the system begins to fail operationally, the failure is the signal for iteration: something in the current configuration is not working, and the inquiry provoked by that failure will eventually reveal what needs to be revised.

This is a pragmatist account of truth, and Chang is explicit about his debts to William James, John Dewey, and the broader pragmatist tradition. But it is a pragmatism that takes the world seriously: operational coherence is not achieved by making claims that are convenient or comfortable but by making claims that genuinely work in practice, that cohere with what inquiry reveals, that withstand the pressure of the remainder that reality generates against every provisional system.

2.4 Activist Realism: Commitment to Learning from Reality

Chang rejects correspondence realism, the view that the goal of science is to produce theories that correspond to ultimate mind-independent reality, because he doubts that we can ever know whether our theories correspond to such a reality or how to evaluate correspondence claims. But he is not an anti-realist. He proposes instead activist realism: a commitment to do everything we can to improve our knowledge of realities, treating reality as what our inquiry is directed at learning from rather than as a fixed structure our theories must correspond to.

Activist realism is a practical and ethical stance toward inquiry rather than a metaphysical claim about the ultimate structure of reality. The activist realist commits to taking what presses back against the current system seriously: not defending the current account against the remainder it generates, but using that remainder to improve the account. Reality is not what we have described. It is what makes our descriptions fail in particular ways, what generates the specific pattern of remainder that tells us how our current closure is imperfect.

3. What Chang Needs

Chang's framework is among the most historically grounded and practically oriented in contemporary philosophy of science. His account of epistemic iteration is supported by detailed historical case studies and connects naturally to the actual practice of scientific inquiry in a way that more abstract philosophical accounts often do not. His activist realism provides a defense of scientific inquiry against both naive correspondence realism and corrosive anti-realism.

There are two questions Chang's framework raises that the closure framework addresses. The first is the structural account of why epistemic iteration works: why starting from an imperfect position and using the outcomes of inquiry to correct the starting point produces progressively better knowledge rather than either stagnating in the same imperfection or generating chaos. Chang demonstrates historically that iteration works and characterizes its structure. The closure

framework provides the structural explanation: iteration works because every closure generates specific remainder, the remainder is informative about exactly how the closure is imperfect, and using the remainder to revise the closure produces a better closure in the specific direction that the remainder indicated.

The second question is the relationship between operational coherence and the world that makes coherence possible and coherence failures informative. Chang's operational coherence is an internal standard: it measures how well a system's components function together. But the world plays a role in generating the failures that reveal what needs to be revised. Chang's activist realism acknowledges this: reality is what generates the remainder. The closure framework provides the structural account: the world that presses back against every closure's predictions is what the closure opens onto, the M that exceeds every constituted fact, the inexhaustible ground from which every closure draws the specific remainder that drives its improvement.

4. The Framework in the Language of Iteration

The closure framework is introduced here in the minimum terms needed to ground Chang's three key concepts.

4.1 Epistemic Iteration as Supersession in the History of Science

A closure regime constitutes facts, generates remainder, and supersedes when the remainder accumulates beyond what the current organizational structure can absorb. Supersession produces a new closure that constitutes the facts the previous closure constituted plus what the previous closure's remainder indicated should be constituted differently.

Epistemic iteration is supersession in the history of science. Each iteration produces a new closure, provisional and imperfect but less imperfect than the previous one, that constitutes the previous iteration's facts plus the corrections that the previous iteration's remainder indicated. The thermoscope generates remainder: its readings vary with the substance used, the fixed points assumed, and the pressure of the atmosphere. That specific pattern of remainder tells the next iteration what to fix: use multiple substances, establish better fixed points, control for pressure. The corrected thermometer generates new remainder, revealing new imperfections, driving the next iteration.

The structural explanation of why iteration improves knowledge is that every closure's remainder is specific: it is not random noise but the precise signature of how the current closure's organizational structure diverges from what it opens onto. The remainder tells you, with increasing precision as iterations accumulate, exactly how the current closure is wrong and what direction revision should take. Chang's thermometer case demonstrates this: the failures of early thermoscopes were not random but specific to particular aspects of the provisional assumptions, and those specifics guided the improvements that produced increasingly accurate instruments.

4.2 Operational Coherence as Closure's Constitutive Integrity

Operational coherence, the smooth functioning of a system of epistemic activities without breakdown, is in closure framework terms what any closure achieves when it constitutes its facts successfully: the organizational structure sustains its distinctions and identity criteria without generating contradiction or failure in its core operations. A closure achieves operational coherence when its constituted facts hold together, when the predictions it generates are confirmed by the measurements it uses, when the standards it applies in evaluation are consistent with the theoretical framework it applies them within.

Operational coherence fails when remainder accumulates to the point of disrupting the closure's core operations: when predictions systematically fail, when measurements produce inconsistent results, when the standards applied to evaluate evidence produce contradictions within the system. These failures are the signal that the current closure has reached the limit of what it can absorb and that supersession is required. Chang's account of how scientists detect and respond to failures of operational coherence is the historical account of what the closure framework calls the accumulation of remainder beyond what the current organizational structure can absorb.

5. Four Claims, One Structure

The vocabulary correspondence between Chang's history and philosophy of science and the closure framework is among the most epistemologically precise in the series. What Chang calls epistemic iteration, the closure framework calls supersession through the history of science: each closure superseding to a better closure by using its remainder as the input for revision. What Chang calls the system of practice, the framework calls the shared closure regime of a scientific community: the integrated set of activities, concepts, and standards that jointly constitute the community's current constituted facts. What Chang calls operational coherence, the framework calls what any closure achieves when it constitutes its facts without contradiction: the smooth functioning that Maturana called autopoiesis and Kauffman called constraint closure at the level of scientific practice. What Chang calls activist realism, the framework calls the epistemic stance of a knower who treats remainder as a resource rather than a threat: commitment to using what the closure cannot absorb to improve the closure rather than defending the current constitution against the pressure it generates. And what Chang calls the imperfect starting point from which all inquiry necessarily begins, the framework calls the only place from which any finite closure can draw distinctions: inside, from where it currently stands, with the organizational structure it currently has.

5.1 Iteration Starts From Wherever the Closure Currently Stands

Chang's most epistemologically important claim is his rejection of foundationalism: science does not start from an indubitable foundation and build upward with certainty. Science starts from where it stands, with the imperfect tools and provisional standards currently available, and uses the outcomes of inquiry to improve those tools and standards. The foundation is always provisional. Progress is real but never final.

The closure framework provides the structural explanation of why this is not only descriptively accurate but structurally necessary. Any finite closure draws its distinctions from inside: it has no access to a view from outside itself, no Archimedean point from which to verify its current constitution independently. It can only revise its current closure using the specific remainder that current closure generates. The iteration begins from wherever the closure currently stands because there is nowhere else to begin. The provisional character of every starting point is not a deficiency to be overcome but the structural condition of finite organizational systems that constitute facts from within.

5.2 Operational Coherence Is the Criterion for Closure Integrity

Chang's operational coherence as a replacement for correspondence truth is the closure framework's account of what any closure achieves when it constitutes its facts successfully, stated in the language of epistemological practice rather than organizational structure. A closure constitutes its facts when its organizational structure draws its distinctions without contradiction and maintains its lawful relationships without breakdown. This is operational coherence: the system of epistemic activities functioning together without disruption.

The rejection of correspondence truth in favor of operational coherence is, in closure framework terms, the rejection of the view that constituted facts must correspond to mind-independent pre-given facts in order to count as genuine knowledge. The closure framework agrees: constituted facts are genuine facts precisely as constituted facts. The apple is red as constituted by the visual system's color-processing closure. The temperature of the water is 100 degrees Celsius as constituted by the thermometry closure. These are real facts, not mere representations of more real mind-independent facts. The operational coherence of the systems that constitute them is the criterion of their integrity. Metzinger's no-self conclusion rested on confusing constituted facts with lesser facts. Chang's operational coherence provides the philosophical rehabilitation: constituted facts are the facts, and operational coherence is the standard by which we assess their integrity.

5.3 Activist Realism Is Commitment to Using Remainder

Chang's activist realism, the commitment to do everything possible to improve our knowledge of realities by taking seriously what presses back against our current account, is in closure framework terms the epistemic stance of treating remainder as a resource. The activist realist does not defend the current closure against the pressure of its remainder. They use the remainder to improve the closure.

This is the epistemological consequence of taking the closure framework seriously: if every closure generates remainder, and if remainder is informative about how the closure is imperfect and what direction improvement should take, then the appropriate epistemic stance is one of active engagement with remainder rather than defensive entrenchment. The activist realist is the knower who treats every failure of operational coherence, every anomaly, every phenomenon the current framework cannot accommodate, as an opportunity to improve the closure rather than as a threat to be dismissed or explained away.

Reality, in Chang's activist realism, is what generates the specific pattern of remainder that tells us how our current closure is imperfect. It is not a fixed structure we are converging toward but the inexhaustible source of the specific pressure that drives improvement. The closure framework calls this M: the inexhaustible ground that every closure opens onto without fully constituting, that generates the specific remainder that drives the closure's improvement across every iteration. Chang's activist realism is the appropriate practical response to the structural fact of M: commit to engaging with what presses back, use what cannot be absorbed to improve the absorptive capacity of the closure, iterate without expecting to reach a final state from which no further remainder is generated.

5.4 Scientific Pluralism Is the Acknowledgment That Different Closures Illuminate Different Remainder

Chang's scientific pluralism, the view that multiple systems of practice can provide valid and complementary knowledge of the same domain, is in closure framework terms the acknowledgment that different closures generate different remainder and therefore illuminate different aspects of what they open onto. Cartwright's dappled world demonstrated this for individual nomological machines. Longino's critical contextual empiricism demonstrated the social conditions for managing it productively. Chang demonstrates it in the history of science: phlogiston theory and oxygen theory both generated genuine knowledge of combustion phenomena, each capturing aspects the other missed and each generating remainder that the other's framework was better equipped to address.

Pluralism is not the abandonment of the pursuit of truth but the recognition that any single closure generates remainder that other closures may be better equipped to constitute. The appropriate response to scientific pluralism is what Longino calls maintaining productive tension among multiple partially valid approaches and what the closure framework calls organizing a community whose collective closure can constitute what no individual closure constitutes alone. Chang's historical case studies provide the richest available documentation of what this looks like in the actual practice of science over centuries of iterative inquiry.

6. Chang and the Grammar of Knowing

Chang occupies a specific position in the series that completes the epistemological arc begun in the Grammar of Knowing and developed through Boroditsky, Longino, and Cartwright. The Grammar of Knowing established the structural claim: all knowledge is grammar-relative, all facts are constituted facts, and no finite closure captures everything. Boroditsky demonstrated this empirically for linguistic grammars. Cartwright demonstrated it for individual scientific machines. Longino demonstrated the social conditions for managing it productively in scientific communities. Chang demonstrates the temporal dynamics of it: how individual closures and the communities that sustain them improve themselves over time through the specific pattern of remainder that each iteration generates.

The temporal dimension is Chang's unique contribution to the series. Every other paper describes the structure of knowledge at a moment: the closure regime, its constituted facts, its remainder, its relationship to what it opens onto. Chang describes the dynamics of knowledge

across time: how closures iterate toward better closures, how the specific pattern of remainder that each closure generates directs the improvement that produces the next closure, how the whole chain of iterations exhibits progressive improvement that is real without being convergent on a final complete account.

For the closure framework, Chang's epistemic iteration provides the historical confirmation that supersession is not a structural claim only but an observable process: the history of science is the history of closures superseding to better closures through the pressure of their own remainder, each iteration beginning from the imperfect starting point of the previous one, each generating remainder that is more informative than the previous iteration's remainder because the improved closure is better positioned to detect the specific ways it is still imperfect.

7. The Grammar of Iteration

The thermometer was calibrated using the boiling point of water. The boiling point of water was measured using the thermometer. The circle is not vicious. It is the entry point into an iterative process that produces progressively better knowledge: better thermometers, better measurements, better understanding of the thermal properties of water and the substances the thermometer contains, better accounts of the physical phenomena involved in phase transitions and heat transfer.

Hasok Chang has spent three decades demonstrating that this is how scientific progress actually works, in thermometry and in chemistry and in the history of measurement more broadly. Science does not start from a firm foundation. It starts from where it stands, using the imperfect tools currently available, generating the inquiries those tools make possible, and using the outcomes of those inquiries to return and improve the tools. The foundation is always provisional. Progress is real. The iteration continues.

The closure framework names the structural logic that Chang's account describes historically. Every closure generates specific remainder. The remainder is informative about exactly how the current closure is imperfect. Using the remainder to revise the closure produces a better closure in the direction the remainder indicated. The improved closure generates new remainder, revealing new imperfections, driving the next iteration. Each iteration supersedes the previous one from within the tradition that the previous one established: building on what the previous iteration got right while correcting what the remainder revealed it got wrong.

Operational coherence is what any closure achieves when it constitutes its facts without breakdown: the smooth functioning of a system of practices that holds together against the pressure of what it opens onto. And activist realism is the appropriate epistemic stance toward a world that is always larger than any closure that engages with it: not defensive entrenchment against the remainder that presses back, but active commitment to using that remainder to improve the closure, to iterate toward better knowledge from wherever we currently stand.

The foundation is never indubitable. The foundation is provisional. That is not a failure of science. That is the grammar of iteration: the grammar of how finite closures improve themselves through the pressure of what they cannot yet constitute, working through time toward a completeness that the structure of closure ensures will never be reached and the structure of M ensures will always be worth pursuing.

References

Chang, H. (2004). Inventing Temperature: Measurement and Scientific Progress. Oxford University Press.

Chang, H. (2012). Is Water H2O? Evidence, Realism and Pluralism. Springer.

Chang, H. (2022). Realism for Realistic People: A New Pragmatist Philosophy of Science. Cambridge University Press.

Chang, H. (2011). The philosophical grammar of scientific practice. International Studies in the Philosophy of Science, 25(3), 205-221.

Chang, H. (2017). Epistemic iteration and natural kinds: realism and pluralism in taxonomy. In K. S. Kendler and J. Parnas (Eds.), Philosophical Issues in Psychiatry IV. Oxford University Press.

Dietz, C. F. (2026a). Consciousness, Closure, and the Cosmos. v3.3.

Dietz, C. F. (2026b). The Grammar of Knowing: What Conscious Knowers Actually Have.

Dietz, C. F. (2026k). The Grammar of Science: Cartwright's Nomological Machines and the Closure Framework.

Dietz, C. F. (2026s). The Grammar of Inquiry: Longino's Critical Contextual Empiricism and the Closure Framework.

Cartwright, N. (1999). The Dappled World: A Study of the Boundaries of Science. Cambridge University Press.

Longino, H. E. (1990). Science as Social Knowledge. Princeton University Press.

James, W. (1907). Pragmatism: A New Name for Some Old Ways of Thinking. Longman, Green and Co.

Dewey, J. (1929). The Quest for Certainty. Minton, Balch and Co.

Kuhn, T. S. (1962). The Structure of Scientific Revolutions. University of Chicago Press.

Author's Note

This paper is the nineteenth in a series engaging thinkers whose work converges with the closure framework developed in Consciousness, Closure, and the Cosmos. Hasok Chang is the Hans Rausing Professor of History and Philosophy of Science at the University of Cambridge, past President of the British Society for the History of Science, and a co-founder of the Society for Philosophy of Science in Practice. His work is distinctive in the series for its sustained engagement with the actual history of scientific practice: unlike most philosophers of science who work primarily with canonical cases, Chang pursues deep historical inquiry into the details of how specific scientific concepts and standards developed over time. His epistemic iteration account emerged from that historical engagement and is therefore grounded in the actual dynamics of scientific progress in a way that more abstract philosophical accounts typically are not. This paper places Chang in explicit conversation with Cartwright and Longino, the two other epistemologists of science in the series. Cartwright's nomological machines describe the structure of individual scientific inquiries. Longino's critical contextual empiricism describes the social conditions for objective knowledge production. Chang's epistemic iteration describes the temporal dynamics: how closures improve themselves over time through the specific pattern of remainder that each iteration generates. Together they constitute the series' complete account of scientific knowledge: bounded, value-laden, socially organized, and capable of iterative improvement. The paper also names the connection to M: activist realism is the appropriate practical response to the inexhaustibility of what every closure opens onto. The author welcomes engagement from Chang directly and from historians and philosophers of science, pragmatist philosophers, and researchers in the practice-based tradition of philosophy of science who find the convergence between epistemic iteration and the closure framework either illuminating or contestable.