Complexity Science and Knowledge-Creation in International Relations Theory

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Summary

This article demonstrates how Lakatos built his systems of justificationism and falsificationism upon the foundation of Curry's formalist mathematics. Its fundamental result establishes the logical status of complexity science as distinct from and superseding those existing systems of proof and refutation commonly acknowledged in social science methodology in particular and scientific epistemology in general. It establishes that this result, concerning the logico-mathematical status of complexity-based scientific reasoning, is not restricted either to the field of international relations theory in particular

or to the social sciences in general. The article begins by setting out significance of complexity science for international relations theory by explaining its epistemological and ontological significance for the level of analysis, scope of analysis, and scale of analysis. It then explains how these points demolish Lakatos's methodology of research programs as an epistemology for scientific progress. In particular, it dissects his construct of the "problemshift" for developments not only within a single research program but also for shifts from one research program to another. For this purpose, it presents a detailed example of theoretical development drawn from applied international relations theory. The example analyzes the succession of Western theories of the domestic politics of Soviet foreign-policy making during the first half of the Cold War. The article analyzes the epistemology of scientific progress inherent in complexity science, as illustrated in that example. It describes this as "complex justificationism," sets it within a "complex scientific-realist" ontology, and sets out, in complexity-science terms, several key issues with which international relations theory has begun to grapple at the beginning of the twenty-first century. It argues how complexity science provides a basis for understanding the interrelatedness of these issues and treating them comprehensively. It underlines that the epistemological undergirding of that argument is valid across fields, disciplines and universes of inquiry.

Glossary

Autopoiesis: The capacity of a complex system autonomously to establish and pursue goals that it has itself generated.

Classical implicative lattice: A mathematical object representing a type of fully ordered set having certain properties.

Complex system: A system having multiple interacting components, of which the overall behavior cannot be inferred simply from the behavior of components.

Complexity science: The study of complex systems.

Epistemogony: A set of logics about hypothesis-generation, (dis)confirmation, and how to generate the consequences (dis)confirmation, that, together with the rules structuring their mutual relationships, produces a class of epistemologies.

Falsificationism: The doctrine that scientific knowledge consists of theories that have not been falsified, rejected, or replaced by other theories. An insistence on falsification (truth) characterizes dogmatic falsificationism; an insistence on rejection (admissibility)

characterizes naïve falsificationism; and an insistence on replacement (a better theory must be ready to hand) characterizes sophisticated falsificationism.

Faraday's criterion: The epistemological premise that a theoretical entity represents a real entity only if it can be shown to have effects by itself and not merely while changing, or acting in concert with other entities.

First-order cybernetics: The cybernetics of systems that are observed, distinguished from those of systems that observe.

Implicative semilattice: A mathematical object representing a type of partially ordered set having certain properties.

Justificationism: The doctrine that scientific knowledge consists of proven or highly probable propositions. An insistence on provability characterizes justificationism; an insistence on high probability characterizes neo-justificationism.

Macrotheory: An articulated preconception concerning a "middle-range" theory that, by including criteria of relevance that are subject to contest, permits not only the theory's results but also its methods to be verified, and that also provides the possibility of those results leading to new middle-range syntheses.

Mesolevel: A level of observation and analysis situated between the macrolevel and microlevel, and mediating their relations.

Peirce's Law: A form of the denial of the Law of Excluded Middle first stated by C.S. Peirce.

Problemshift: Lakatos's original term, describing how empirical findings influence a research program's epistemology and ontology, discarded early on, when he began to concentrate on developments within individual research programs, never directly addressing how one research program supersedes another.

Scientific realism: An epistemogony according to which the world is independent of our knowledge-gathering activities and science is the best way to explore it.

Second-order cybernetics: The cybernetics of systems that observe, distinguished from those of systems that are observed.

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1. Introduction

Complexity science is the study of complex systems. A complex system is a system having multiple interacting components, of which the overall behavior cannot be inferred simply from the behavior of components. Complexity science spans scales from particle fields to information mechanics (physical analysis of the dynamics of information transmission) and adaptive systems (learning and consciousness, including neural systems), to human society, ecosystems and extraterrestrial space. These phenomena all share the qualities of a self-organizing network. From their study, new methodologies and concepts of the nature of reality have emerged. In international relations, the emergence of an interconnected global civilization manifests this sort of complexity. In knowledge-creation, so do the cross-fertilization and merging of academic specializations into ever newer and more numerous interdisciplinary subfields.

The next section below sets out import of complexity science in general and for international relations theory in particular. The epistemological and ontological significance is explained for the level of analysis, scope of analysis, and scale of analysis. Then it is explained how these points demolish Lakatos's methodology of research programs as an epistemology for scientific progress. In particular, it dissects the construct of the "problemshift" for developments not only within a single research program but also for shifts from one research program to another. For this a detailed case study is also given, drawn from applied international relations theory. The epistemology of scientific progress inherent in complexity science is then analyzed, and it is described as "complex justificationism" within a "complex scientific-realist" ontology. The conclusion sets out in complexity-science terms, a few non-exhaustive issues with which international relations theory has recently begun to attempt to deal. It indicates how complexity science captures their interrelatedness and provides the foundation for their comprehensive treatment.

2. Complexity Science: Its Epistemological and Ontological Significance

"Complexity" is neither complicatedness, overdetermination, nor a multiplication of explanatory variables. It is not merely a new implement to be added to an existing

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theoretical tool-kit. Complexity science is a fundamentally new way of looking at physical, biological, and social phenomena. It is a cross-disciplinary field with its own approach to knowledge-creation that includes a set of methodological approaches to problematization. As such, it offers distinct and innovative perspectives on the evolution international systems and on the behaviors of actors in them. Certain insights are valid universally across all complex phenomena. These insights are epistemological and ontological. They concern the level of analysis, the scale of analysis, and the scope of analysis.

2.1. Issues of the Level of Analysis Focus on Emergence

Issues of the level of analysis draw attention principally to the category of emergence. Emergence is the evolution of new (qualitative) phenomena through a system's interaction with the environment. Ontological issues concerning the level of analysis include the dependence of the whole on parts, the interdependence of parts, and specialization of parts. Since studying parts in isolation does not work, a good place to start is to look at how changes in one part may affect the others and the behavior of the whole. The increased political-science interest in counterfactuals in the 1990s, after the end of the Cold War, reflects how unavoidable this aspect of complexity has become after the top-down international hierarchy of that era collapsed.

The reconstruction of the international system from the bottom up after the Cold War thus presents issues concerning the level of analysis of which complexity science offers distinctive treatment. The multiplication and incorporation of new issue areas in international politics and security manifest nothing less than an emergent quality of knowledge that reflects the complexity of the real world. This includes the whole growth of questions about deterritorialized aspects of international politics. Specifically, it adds problems of boundary-definition in issue-area space to those that are evident in geopolitical space. Concerning the latter, the reconfiguration of international regions in the early twenty-first century and their increased relative autonomy of great power conflict, in comparison with the Cold War system, are exemplary. Although distinctions among superpowers, great powers, and regional powers have not disappeared, middle-range and lower-level phenomena have become the predominant motive forces in an international system that self-organizes from bottom up.

Epistemological issues concerning the level of analysis force the analyst to recognize that describing the behavior of a system in response to its environment is neither straightforward nor uncomplicated. Since the amount of information available and necessary for such description grows exponentially with the complexity of the

environment, psychological behaviorism—indeed any strict phenomenology at all—is ill-founded. That is because, in such an information-rich environment, the use of inference to obtain description and analysis from small amounts of information becomes problematic. The significance of how we think (or fail to think) *about thinking* is thus enhanced.

2.2. Issues of the Scope of Analysis Focus on Stability and Change

Also there are issues of the scope of the analysis. These draw attention principally to the dual category of stability-and-change. This category subsumes adaptation, pattern formation, and evolution. As such, it forces the question of learning, including organizational learning. It also balances issues of emergence (such as transnational networks about nonterritorial issues) with equally important territorial aspects of world politics (such as the self-organization of regional international systems and the relations among them).

Ontological issues concerning the scope of analysis raise still deeper questions about the relationship between the whole and the parts. A complexity-based focus on stability and change establishes that multiple stable states exist (i.e., not just "Nash equilibria") as well as meta-stable states. If and when a single component of a system controls its collective behavior, then the collective behavior cannot be more complex than the individual behavior. The superpower nuclear bipolarity of the Cold War is an example showing how a dominant component of a system can restrain its collective behavior. In such an instance, there is no emergent complexity, and the question of stability and change hardly arises. Yet new complex systems may be formed from the recombination of parts or aspects of other complex systems. Indeed, such composites permit rapid evolution.

Epistemological issues concerning the scope of analysis under complexity, like those concerning the level of analysis, raise questions about the use of inference to obtain the description from a seemingly smaller amount of information. The use of inference in such a situation leads to the concept of "algorithmic complexity." This in turn raises such issues as the relationship between descriptions and systems, the connection between theory and simulations, and about the conceptual status of models used in simulations.

2.3. Issues of the Scale of Analysis Focus on Self-organization

Issues of the scale of analysis draw attention to the category of self-organization. Epistemological issues about the scale of analysis arise from the fact that under complexity, fine scales influence large-scale behavior. To understand complex systems

therefore requires multi-scale descriptions. Yet the degree of complexity that is apparent, also depends on the scale at which the system is described. Ontological questions about the scale of analysis arise from the fact that the apparent complexity of a system depends on the scale at which the system is described. For example, a requirement of complexity on a large scale is to establish correlations on a small scale: these reduce the overall (though not necessarily everywhere local) smaller-scale complexity. A complexity-theory concept that we may call "mesolevel" structuration cuts through the "structure-vs.-agent" knot. The transformation and succession of international orders, for example, is triggered by properties emergent from (re)structuration on the mesolevel.

Self-organizing international regions, manifesting as emergent multilateral networks, are the categorical phenomenon characterizing the post–Cold War transition. These include not only continental regional international subsystems (e.g., Europe and Southeast Asia), but also littoral regional international subsystems (e.g., Pacific Rim, Baltic, and Caspian). Self-organization at the mesolevel is an emergent quality of the complex system. The new territorial aspects of contemporary world politics thereby lead to the concept of self-organized criticality. That in turn invites consideration of the global political system and its components as complex adaptive systems. From this it would follow that those systems are capable of learning and of pro-active behavior that shapes their own environment. The character of the post–Cold War transition is as the problematization of nontraditional issue areas of international public policy in security terms (e.g., environmental security, human security). The task of policy analysis in a self-organizing complex system is to identify crucial intermediate points where cognitive and organizational intervention will instantiate large-scale restructuring of the system itself.

It follows from the ontological components of complexity science, that the definition of a research problem has no *a priori* referent in the world at large that is independent of the researcher's reflection. The application of complexity science to international relations theory therefore opens fundamental questions. Since the traditional analytical distinctions that once structured the "levels of analysis" problem are no longer valid, the standard solution to that problem is no longer reliable. For example, the emergence and incipient consolidation of regional international systems, as a distinctive characteristic of the global post–Cold War transition illustrates that the three standard levels of analysis—the individual, the state, and the international—are no longer collectively exhaustive. The new situation requires not only new theoretical categories but also new categories of theory and new concepts of knowledge creation.

3. How Complexity Science Overthrows Lakatos's Methodology of Research Programs

Complexity science recognizes that the world has a different nature than heretofore supposed. It thus challenges the criteria according to which theories are to be judged and the methods by which knowledge is to be cumulated. In particular, the models of reasoning that are required to deal with a complex world must go beyond the well-known Lakatosian formulae of the five types of justificationism and falsificationism. Complexity science opens a new way to create knowledge about the world, because it is founded upon the interdependence between that knowledge and this world. It does not require either the adoption of relativism or the introduction of anarchy into the market of ideas. It merely establishes that we have reached a stage in theory-construction where Lakatos's well-known and widely adopted model of scientific progress, called "the methodology of scientific research programs," no longer adequately describes the creation of scientific knowledge.

3.1. The Meaning of a "Problemshift" under Complexity Science

To assist in such a clarification, it is useful to introduction the notion of "epistemogony." Just as a cosmogony may generate a class of theories of cosmology, or Hesiod's *Theogony* generated the class of theologies that are collectively called classical Greek mythology, so an epistemogony may be said to generate a class of epistemologies (e.g., Popper, Kuhn, Lakatos). For example, scientific realism is an epistemogony. The comparative examination of Popper, Kuhn, and Lakatos reveals that an epistemogony has three components: a logic of hypothesis generation, a logic of hypothesis testing (i.e., a logic of the process of confirmation), and a logic of generating consequences from (dis)confirmation. In any epistemogony, each of these may be either inductive or deductive. Under scientific realism, at least two of the three must be deductive. Table 1 summarizes the distinctions here immediately enumerated. It also adds ontological and epistemological distinctions that are fully explicated below and in Table 2. On this basis it is possible to distinguish systematically among Kuhn, Popper, and Lakatos.

1. Popper is completely syllogistic: he is deductivist regarding the logic of hypothesis generation and treats the logic of the process of confirmation, also in deductivist manner, as inseparable from the logic of generating consequences from (dis)confirmation.

2. Kuhn's challenge to Popper asserts the logic of hypothesis generation to be inductive: thus the role of the "critical experiment." However, Kuhn remains deductivist as regards the logic of hypothesis testing. Like Popper, he did not explicitly distinguish between the

epistemological status of the confirmation process itself *versus* the process of generating the consequences of (dis)confirmation. This nevertheless threatened to overthrow Popper's model of the progressive cumulation of knowledge.

3. Lakatos's attempt to save Popper consisted, first, in maintaining, against Kuhn and with Popper, that the logic of hypothesis generation remained deductive, not inductive; and, second, in splitting the hypothesis-testing logic into a logic of confirmation and a logic of the generation of the consequences of (dis)confirmation. To confound Kuhn, Lakatos admitted that the logic of the confirmation process might be inductive. To conserve Popper's premise of the progressive cumulation of knowledge, however, he maintained that the consequences of disconfirmation were deductively, not inductively established. Lakatos's vehicle for this revision was his splitting the research program into a "positive heuristic" and a "negative heuristic" (of which the latter he subsequently re-labelled the "hard core," dropping the adjective from the former), and his adjoining to the latter of a "protective belt" proper to the given research program. By this artifice he was able to suggest that an otherwise apparently anarchic succession of Kuhnian paradigms in fact represented the development of theory within a single research program.

Logic of:	**POPPER**	**KUHN**	**LAKATOS**	**COMPLEXITY SCIENCE**
•Hypothesis generation	Deductive	Inductive	Deductive	Deductive
•Hypothesis testing (same as Process of confirmation)	Deductive	Deductive	Inductive	Deductive
•Generating consequences of (dis)confirmation	Deductive	Deductive	Deductive	Inductive

Table 1. Popper, Kuhn, Lakatos, and Complexity Science Distinguished as to Their Logics.

Table 1 summarizes and explicates these differences. Table 2 distinguishes them through the use of Feyerabend's enumeration of types of scientific realism, which he developed from an inspection of the history of modern physical science, and without direct reference to Popper, Kuhn, or Lakatos.

Logic of:	**Type of Scientific Realism (Feyerabend's taxonomy)**	**Ontological and epistemological premises**
Popper	**First type:** Positive knowledge is philosophically assumed to be possible. Theories are nonfalsifiable on their own terms.	*Ontological and epistemological premises are not distinguished.* A theory is true not just because it fits the facts but because it (1) leads to novel predictions *and* (2) does not fail when applied to similar topics. It remains true whether one begins with premises and passes to observations, or vice versa.
Kuhn	**Second type:** The purpose of theory is to delimit reality.	*Ontological premise:* Scientific theories introduce new entities with new properties and new causal effects. However: *Epistemological premise ("Faraday's criterion"):* A theoretical entity represents a real entity only if it can be shown to have effects by itself and not merely while changing, or acting in concert with other entities.
Lakatos	**Third type:** Research programs succeed one another through empirical falsification. However, two mutually incommensurate heuristics may coexist. Problemshifts are definitional.	*Denies ontology.* *Epistemological premise(s):* Two-layer model of knowledge: Theoretical issues are not ontological but involve the choice among systems of correlations of sense impressions.
Complexity Science	**"Mach-Maxwell" type:** Complexity-generated processes of emergence produce problemshifts that appear to motivate the revision of a research program's heuristic. However, the heuristic cannot be considered isolated from the hard core: problemshifts modify the hard core.	*Ontological premise:* Theoretical entities do not represent any real entities unless the phenomena follow the hypotheses in every detail. *Epistemological premise (drops Faraday's criterion):* The interpretation of an observation language is determined by the theories which are used to explain what we observe, and such an interpretation changes as soon as those theories change.

Table 2. Popper, Kuhn, Lakatos, and Complexity Science Distinguished as to Their First Premises.

1. The first type of scientific realism does not differentiate in practice between ontology and epistemology. According to it, a theory is verified not simply by fitting the facts; it must lead to novel predictions *and* not fail when applied to topics similar to those where success was achieved. This accords with Popper's conceptions.

2. The second type of scientific realism posits ontologically that scientific theories introduce new entities with new properties and new causal effects but adjoins to it the epistemological requirement, which Feyerabend calls "Faraday's criterion," that a theoretical entity represents a real entity only if it can be shown to have effects by itself and not merely while changing, or acting in concert with other entities. Faraday's criterion reveals that this second type of scientific realism is constrained by the epistemic limitations of field theory.

3. The third type of scientific realism denies that theories are ontological at all. It maintains that the choice among systems is only a choice among correlations of sense impressions. It amounts merely to asserting that one depicted image of such correlations is preferable to another. Indeed, its corresponding philosophical doctrine of the reality of the external world asserts nothing other than such a preference. This notion accords with Lakatos's conceptions and is so strongly informed positivist investigations that Feyerabend called it the "positivistic version" of scientific realism. As Tables 1 and 2 indicate, there is a fourth type of scientific realism that Feyerabend mentions. For it he gives the examples of Mach and Maxwell. He does not comprehensively develop it. *This fourth type of scientific realism is the type of scientific realism proper to complexity science.* Its ontological premise is that theoretical entities do not represent real entities unless the phenomena follow the hypotheses in every detail. Its epistemological premise is that the interpretation of an observation language is determined by the theories used to explain observations, and that interpretation changes as soon as those theories change.

This is understandable in light of Feyerabend's analysis of the varieties of justificationism. It sheds light on the recent development of "rationalist" international relations theory. What Feyerabend calls the probabilistic approach to justificationism—the same as Lakatosian neo-justificationism—typifies statistics-oriented behavioralism. This has lately lost much of its intellectual hegemony, if not legitimacy. This crisis of social-science behavioralism in international relations theory explains the positivists' panicked search of the extra-disciplinary literature on nationalism for conceptual tools after the end of the Cold War. This search culminated in the marriage between neorealism and neoliberalism under the tent of rational choice theory. This marriage represents nothing other than the further depsychologization of the conceptual apparatus. It is a choice in favor of what Feyerabend calls the transcendental-idealist solution to justificationism. Its shortcomings notably include its reduction of the national interest to mathematized "self-preservation." The early post-Soviet exploration of nationalism by social scientists, as a basis for international relations theory requiring the systematic and rigorous reintroduction of the multidimensional analysis of the national interest, manifested the solution that Feyerabend counterposes to probabilism as well as to transcendental-idealism, and which he calls conventionalism. The nature of

conventionalism describes so well the intrinsic method of complexity science that it is worth an extended citation. It will be seen that this completes the description of the fourth type of scientific realism schematized in Table 1.

Conventionalism says that a theory is justified because it brings some order into the known facts and provides concepts and ordering principles for things as yet to be discovered. The order is never complete, for there are always recalcitrant phenomena. This does not invalidate the chosen scheme but challenges its defenders to rebuild the phenomena until they fit into it. The scheme is chosen either because it easily accounts for some empirical regularities (empirically motivated conventionalism), or because it follows from certain theoretical postulates (the Dinglerian version, an exegesis of Mach). Once the scheme is accepted and incorporated into scientific practice, it quite automatically transforms the facts and thus removes any criticism "on the basis of experience."

This Mach/Maxwell type of scientific realism also fills an important lacuna in Lakatos. Specifically, it answers the question as to how "problemshifts" motivate the evolution from one research program to another. According to Lakatos, the replacement of one research program is in fact a special kind of problemshift. However, he used the idea of a problemshift to focus on typologizing the varieties of progress and degeneration within individual research programs. According to him, a problemshift occurs when *ad hoc* auxiliary hypotheses and other devices in a research program's protective belt are integrated into a new and more robust heuristic which does not explicitly challenge the assumptions in the research program's hard core. He neglected to pursue the question how such a problemshift may in fact be an intermediate term leading directly to a challenge to the hard core itself. In fact, such an interpretation is more central to understanding scientific progress. Indeed, in Lakatos's original formulation, a research program's hard core remains irrefutable on its own terms. Progress from one theory to another within a single research program can come about only through consistent violations of the antecedent theory's own logical and theoretical postulates. However, the way towards this can be opened *only* by a modification of the research program's "heuristic": cracking the hard core, as it were.

A problemshift represents such a crack in the hard core. It seeks to protect the research program's heuristic "progressively," by generating auxiliary hypotheses in its protective belt. At the same time it provides corrective lenses through which to focus more clearly on those things being observed. Lakatos skirts the issue of exactly how this may lead to the implosion of a hard core under the pressure of supernumerary "auxiliary hypotheses." This process is adaptive and its consequences are transvaluative. An example is given below. From the transformative destruction of a hard core, there emerges a new research

program with a new hard core, which is nonetheless born of the "problemshifted heuristic" of the old research program. The notion of a problemshift thereby reveals a research program, likewise, to be only a *Gestalt*.

This fourth type of scientific realism describes scientific progress during the Cold War in the analysis of the domestic mechanism of Soviet foreign policy formation. Table 3 shows the dynamic of this evolution at work, and how Lakatos failed to be able to account for it. We may consider the evolution of Western theories of Soviet foreign policy making during the Cold War to be a case study of the succession of research programs. This research question is precisely a complexity-related issue, because it was exactly the increasing complexity of Soviet organizations and cognitions, with which western Sovietologists had the greatest difficulty coping. Altogether five theories of Soviet foreign policy making may be distinguished, revealing two cycles in the problemshift-motivated succession of research programs via the modification of hard core. However, for reasons of space limitation and the scope of this article, I restrict this demonstration to only one cycle the evolution of such theories. This corresponds to the development of western Sovietology from roughly 1945 to 1970. Table 3 summarizes that cycle, which is explicated in the following section.

3.2. An Example of the Crucial Nature of a "Problemshift"

The traditional point of departure for the study of Soviet foreign policy formation was the totalitarian theory. According to this, no organizationally-based explanation of the mechanisms of Soviet foreign policy making was necessary, for a single set of immutable rules—an "operational code"—prescribed Soviet foreign policy behavior. Implicit in that theory was the assumption that this behavior was highly deterministic, wholly unreactive to external stimuli, fully resistant to change, and therefore incapable of learning. Also implicit in this theory, for which Stalin's regime was the evidence, was the assumption that the system did not allow any competing interests.

Useful as the totalitarian theory was for understanding the Stalin era, it did not begin to capture the evolving complexity of the post-Stalin system. To begin with, the succession to Stalin did not conform to the totalitarian theory. According to this, political conflict should occur only during succession crises, and a new dictator should promptly consolidate power and maintain it unchallenged. This postulate became implausible after 1955, when Khrushchev and Bulganin established themselves a duumvirate. The study of the Stalin succession and the resistance of the Stalinists to Khrushchev even after his 1956 de-Stalinization speech led Sovietologists to what was eventually called the

"conflict-school" theory of Soviet politics. Like the totalitarian theory, this included a domestic-political explanation of Soviet foreign policy.

The conflict-school approach led to the elaboration of a new macrotheory. *A macrotheory is neither a research program nor a theory.* What distinguishes a macrotheory from a research program is its capacity to generate new syntheses at the level of middle-range theory. Here we are able to get a handle on the function of a heuristic inside a research program, and how and why it evolves. *The difference between a heuristic and a macrotheory is that a macrotheory can provide continuity across research programs.* Lakatos's distinctions among empirically and theoretically progressive and degenerative research programs do not take account of the crucial need to be able to account for the evolution of the heuristic. It cannot account for how new research programs generate themselves from existing research programs. According to Lakatos, this seems a rather idiosyncratic and sociological process. To be sure, there are important elements of that. But it is not entirely a random process. A complexity-based approach to knowledge creation fills this lacuna. *A macrotheory bridging two research programs is the vehicle by which changes in the heuristic, brought about by the "progressive" incorporation of auxiliary hypotheses from the protective belt, are transmitted to the old research program's hard core, cracking it.* (In a non-Lakatosian epistemology that does not falsely insulate the "negative heuristic" and "positive heuristic" from one another, the concept of a macrotheory may not be required or may take a different form.)

According to the totalitarian theory, no organization played any important role in Soviet foreign policy making, because the will of the totalitarian dictator was determinant. The conflict-school theory, by contrast, recognized the significance of one organization: the Politburo. However, it focused upon the Politburo only as a forum for conflict among its members and not as an organization per se. Yet whereas the totalitarian experience considered the constant struggle for political supremacy to characterize Soviet politics only during succession struggles, proponents of the conflict-school approach considered it as a domestic political process relevant to foreign policy making, but one that did not exhibit any behavioral regularities. However, once the conflict-school theory admitted the permanence of intra-elite conflicts as a matter of principle, it became inevitable that some analysts would begin to look for regular patterns of elite conflicts. In particular, they looked for institutional bases of such conflicts. Analysis thereby shifted from the struggle over personal power to that over policy substance. Rivalries among institutions became the fodder for analysis.

The institutional-group theory arose as Sovietologists adopted the analytical distinction between conflict resolution within the elite on the one hand, and, on the other hand, interest aggregation and articulation throughout the broader political and social system.

The latter evolved from the conflict-school theory and typically distinguished between Soviet interest groups that had domestic organizational goals leading them to benefit from international tensions, and those having such goals leading them to benefit from the relaxation of international tensions. These groups he defined occupationally.

	TOTALITARIAN RESEARCH PROGRAM		**POSTTOTALITARIAN RESEARCH PROGRAM**	
HARD CORE *(What Is the Source of Soviet Conduct?)*	The nature of totalitarianism.	Marxist-Leninist doctrine (*institutionalized as totalitarianism).*	Marxist-Leninist doctrine (*institutionalized as the post-Stalin system).*	[Hard Core of Post-totalitarian Research Program, Revised by Modified Heuristic]
	Totalitarian Macrotheory	**Elite-Conflict Macrotheory**		**[Bridge to Successor to Post-totalitarian Research Program]**
THEORY	***TOTALITARIAN***	***CONFLICT-SCHOOL (Noninstitutionalized Conflict)***	***INSTITUTIONAL-GROUP (Institutionalized Conflict)***	***[New Posttotalitarian Theory]***
HEURISTIC *(What Is the Domestic Mechanism through Which Soviet Foreign Policy Is Made?)*	*A single set of governing beliefs* ("operational code") determines Soviet foreign policy behavior.	*A single set of governing beliefs* consonant with Marxist-Leninist doctrine (and Soviet national interests) is the basis for resolving foreign policy issues in the long run, but leaders may manipulate them in the short run.	Policy differences among leaders reflect regular institutional interests that are more enduring than succession struggles. In specific instances, general policy predispositions are conflated with particular policy preferences.	[Modified Heuristic within the Posttotalitarian Research Program, revised to integrate the "Auxiliary Hypo-theses" of the Institutional-Group Theory]
AUXILIARY HYPOTHESES *(How Deterministic and Immutable Is Soviet Foreign Policy? How Reactive to External Stimuli?)*	Policy is highly deterministic and resistant to change, and totally unreactive to external stimuli.	Long-run policy change is possible due to domestic factors but minimal reactivity to external stimuli makes it effectively impermeable to outside influence.	Policy is somewhat voluntaristic and reactive to external stimuli. Indeed, certain segments of the bureaucracy may respond to outside influence.	["Auxiliary Hypotheses" Subsequently Generated to Protect Modified Heuristic]

Table 3. Research Programs and Theories (1945–*ca.* 1970) of Soviet Foreign Policy Making, with Macrotheories Explicated.

For example, the military was assumed to prefer tension because this increased its budget, whereas light industry was assumed to prefer the absence of tension because it wanted part of that budget. This theory analyzed Soviet policy making to see how those institutions formed coalitions domestically to pursue foreign policy goals that they had in common to satisfy domestic constituencies. According to the institutional-group theory, conflict occurred in Soviet foreign policy making not only among leaders and the institutions they ran but also among those institutions independently of leadership conflict. This development was related to changing conceptualizations of the Soviet political process generally. It addressed broad policy predispositions rather than particular decisions. Indeed, when the general interest-group technique was applied to the analysis of foreign policy making, it was limited by the implication, in fact made explicit by the institutional-pluralism approach, that institutions were unitary and monolithic, with unambiguous interests.

The shift from the conflict-school theory to the institutional-group theory was motivated by the accumulation of auxiliary hypotheses in the totalitarian research program's protective belt. Like the move from the totalitarian to the conflict-school theory, this entailed an explicit modification of the totalitarian research program's heuristic. Such a modification is the dynamic characteristic of a "problemshift." Under the problemshift that motivated the revision of the totalitarian theory into the conflict-school theory, it was still possible to conserve the research program's hard core apparently unchanged. As is evident from Table 1, however, the hard core was in fact modified. As explained above, the move from the conflict-school to the institutional-group theory also manifests a problemshift. It entailed a further modification of the totalitarian research program's hard core, to the point where the appearance of a new research program became undeniable. The bases of the posttotalitarian research program were clarified by a subsequent problemshift not depicted in Table 3, motivated by a further evolution of the research program's heuristic and confirming definitively the downfall of the totalitarian research program.

The "heuristic" of any macrotheory asks questions about the domestic mechanism that formulates Soviet foreign policy, and specifically about the cognitive and organizational constraints governing the production of such policy. Let us take these one at a time. As to cognitive constraints, the questions are whether general predispositions and policy-specific attitudes are conflated with each other or separated within a cognitive framework; and whether there exists one comprehensive "operational code," or two or more competing operational codes, or none at all. The next development in Soviet foreign policy making analysis was a field/ground shift that focused not on the institutions as harboring individuals having ideas but on the ideas themselves, and which treated the

individuals merely as their carriers. It assumed that organizations were not monolithic but could be fragmented, and that the USSR could learn international behavior voluntaristically. However, since political science as a discipline had not internalized enough cognitive psychology and organizational science at that time, the step was never taken to integrate this development into a fully fledged theory. Since the concepts of complex systems did not exist at that time, moreover, the step that would then have followed—to a third research program—was likewise never made.

4. The Logical Foundation of "Complex Justificationism"

The reason why Lakatos's methodology of research programs is invalid, is not that he generated it from a case study of the history of mathematical thought, specifically the growth of knowledge regarding Euler's work on polyhedra. Nor is it because a consensus has formed among mathematicians that this limited field is itself atypical among mathematical topics from a growth-of-knowledge standpoint, such that Lakatos's "methodology of scientific research programs" is atypical of how most mathematical knowledge is generated.

In Lakatos's construction of "sophisticated methodological falsificationism" (by which he contrived to save Popper from Kuhn), auxiliary hypotheses and other elements are generated in the "protective belt" surrounding the research program's "(negative) heuristic," which in turn insulates its "hard core." But this "methodology" is intrinsically incomplete, because the capacity for modification of a research program's protective belt in Lakatos turns out to be equivalent to the adjoining of Peirce's Law to the negation system called "simple refutability." According to simple refutability, a system is falsified if any one of its elementary propositions is falsified. (Simple refutability is equivalent to what Lakatos called "dogmatic falsificationism." In logico-mathematical contexts, it is also called "minimal negation." See Appendix 1.) Peirce's Law in effect posits that if A intersects B — imagine two circles in a Venn diagram — then the intersection of A with that part of B lying outside A, is not the null-set but rather the arc of the circle A that is inside the circle B.

In this logic, applying Peirce's Law, the law of excluded middle does not hold, and the intersection of A with B, excluding the arc A's boundary in B, is called the pseudocomplement of the part of A lying outside B. The pseudocomplement is the interior of the complement. If Peirce's Law is what makes possible the "sophisticated methodological falsificationism" of Lakatos, then the self-increase of the heuristic's content in this generative manner may be represented as the achievement of width by the

arc of circle A that is contained inside circle B. However, Lakatos does not examine how such additional propositions (which do not appear from out of nothing) find their way into the protective belt. Therefore, he fails to see that any increase in the content of the protective belt in fact entails a modification of the content of the heuristic. The consequence of this blindness is his failure to articulate how one research program succeeds another. By contrast, this article offers a case study in the consecutive succession of research programs. I now state in general terms the dynamic of that succession as observed in the particular case here presented.

Complexity science identifies two ways for such additional propositions to find their way into the protective belt. The first possibility is that an elementary proposition in the heuristic is considered multiple rather than singular and is split into two or more constituent elements, one of which may be taken outside ("alienated from") the heuristic into the protective belt. The above discussion of theories of Soviet foreign policy making illustrates how it is impossible to generate auxiliary hypotheses without introducing surreptitious modifications into the research program's heuristic.

The second possibility is that an elementary proposition in the heuristic is considered—or found to be—multiple rather than singular. (A related possibility is that two singular propositions in the heuristic may generate a third.) In these latter cases, a proposition originally thought to be elementary generates one or more new propositions within the Lakatosian heuristic itself. These newly generated propositions are emergent in the complexity-informed sense and must be considered elementary rather than composite. In either instance, the content of the heuristic is altered. Indeed, the "structure-based" school of complexity may be situated as a subdiscipline of Peircean semiotics. This representation opens the door to a complexity-informed consideration of the growth of scientific knowledge. If one sought a Lakatosian name for the proof methods of complexity science, "complex justificationism" would be appropriate. However, it must be stressed that this carries a concept of "proof and refutation" that lies outside the compass of Lakatos's classification of five methodological systems of justificationism and falsificationism. It indeed overthrows Lakatos's whole ontology of scientific knowledge, as well as his epistemology of its cumulation, in favor of a Feyerabendian orientation. At the same time, it would be necessary to emphasize the need to explore further what we may call the "complex scientific-realist" ontology within which that epistemology would be situated. Appendix 1 summarizes longer work that demonstrates how complex justificationism is situated in relation to the five methodological systems that Lakatos identifies.

5. Conclusion: A Further Agenda for Complexity Science in International Studies

It was pointed out at the beginning of this article how complexity-informed approaches to the study of international relations indicate emergence, stability/change, and self-organization as categories for special attention. The ensemble and intersection of these categories suggest strongly that both the international system as a whole, as well as the actors in it (including nonstate actors) and even subsets of those actors (e.g., individual ministries within state bureaucracies), deserve scrutiny from the standpoint of complex adaptive systems and autopoietic learning. This emphasis on autopoietic behavior—the ability of a complex system autonomously to establish and pursue its own goals—distinguishes second-order from first-order cybernetics. Certain types of agent-based modelling have already shown themselves to be a unique methodological innovation of complex-science methods in the social sciences. However powerful such a technique is, it should not be pursued to the exclusion of other reflective approaches. They are certainly not to be confounded with "rational choice" despite a similarity of the operational instrument, mathematization.

In international relations theory, such volitional concepts are certainly absent (save in an extremely constrained utilitarian sense) from the rational-choice school of international relations theory. And to be sure, during the greatest part of the Cold War, the thesis that Soviet foreign policy was capable of learning was a minoritarian view. Yet it is correct to say that political science as a whole did not have an adequate theoretical apparatus for understanding any such learning. This did not prevent some scholars from building useful frameworks, but there was not enough "critical mass" to allow one to speak of a school or a trend, much less a paradigm or a research program. Even so, not even psychology had the methodological and operational tools for specifying such learning until the 1980s.

The significance of the case study of theory development given in the preceding section is in the recalcitrance of some sectors of political science as a discipline, particularly in North America at the end of the twentieth century, to consider the possibility of organizational learning. This is due to the fact that the governing sociology of knowledge of that time and place remained gridlocked in the mechanistic first-order cybernetic systems theory inherited from structural functionalism. It is more an effect of political science than of systems theory per se. However, systems theory in a second-order cybernetic framework—the cybernetics of observing systems as opposed to the cybernetics of observed systems—is able to incorporate rich insights from complexity science.

The reason why certain trends, in North American political-science in particular, have militated against considering political systems of whatever order and scope to be capable of autopoiesis, is the inheritance of the specifically structural-functional approach to systems analysis, in turn due primarily to the influence of Gabriel Almond, a student of Talcott Parsons. But what Parsons most missed in his exegesis of Weber was the dynamic interplay of factors that is evident in any comprehensive analysis of any historically developed phenomenon. Parsons sacrificed this idiographic sensitivity to nomothetic striving. As a result, the schematization of social and political phenomena superseded their situation (contextualization) in human space and time. An implicit teleology thus infected interpretations based on the schema: the criticism of structural-functionalism for a bias towards social homeostasis is well known. The goals of action were set by the universalist theoretical construct, not by the actors' autonomous ratiocination. When schema supersedes context, then the analysis prohibits the actors from appearing to set their own goals: whereas autopoiesis means precisely to set one's own goals, whether one is a person, an organization, or a social system.

Political scientists and other historians of contemporary international affairs need to understand better the origin and distinguishing features of complexity science, and its development in its full variety from the early 1970s in life science and physical science. Complexity science is not solely the realm of agent-based modelling. Much qualitative empirical work on the evolution of norms, for example, is compassed by the complexity-science category of autopoiesis. This having been said, it is perhaps appropriate to limit this sketch of a research agenda for complexity science in international relations theory, to only three brief concluding observations.

1. The international system as a whole and the actors in it are all are complex systems.

2. Complexity science dissolves the "agent-structure debate."

3. Complexity science illuminates the existence of a new type of division of labor in world society, *viz.*, the network.

To conclude. We may speak of a "complex" (or "networked" or "distributed") division of labor as a third type now evident in social organization, including international affairs, and superseding the two classic forms distinguished by Durkheim. An overemphasis on either hierarchy or subordination—on structure or agent, or even on the agent/structure duality to the exclusion of other terms—is one-sided. The simultaneous presence of "structure" and "self-structuring"e is one of the differences between a hierarchy and a

network. Complex systems are networks more than they are hierarchies. It is this simultaneous presence of structure and self-structuring (which latter gives rise to autopoiesis) that yields the emergent and self-organizing qualities of world politics that are most characteristic of complex systems.

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Appendix 1

This Appendix sets out how the five methodologies identified by Lakatos are related and how the epistemology that informs complexity theory differs from them. Lakatos's typology includes three systems of falsificationism and two systems of justificationism. He based them, without saying so, on the five "systems of negation" set out among the fundamentals of mathematical logic according to the formalist school of mathematics, as presented by Curry, who denotes them as various types of refutability and absurdity. There can be little doubt that Lakatos, whose original training was as a philosopher of mathematics, was familiar with these. He represented these systems of negation as epistemologies for scientific research that he inductively constructed from his historical review of the evolution of scientific method, and he gave them different, more expressive names. (See Table 4.)

Neither formalist mathematics nor Lakatos sought either to systematize these relations or to establish a comprehensive and exhaustive systematic account of such relations. Therefore, no part of the systematization in Table 4 is to be found in Lakatos's work. It is, in fact, a complete systematization. Moreover, the full and exhaustive range of all relationships, including idempotent ones, is internally consistent. These relationships are established on the basis of Lakatos's discussion of the different methods, including his adaptation of mathematical logic as set out in the basic works of the formalist mathematical school. However, only the relationships most salient to this article have been indicated, and only for the purpose of explicating briefly the corresponding assertions in the body of the article itself.

Denotation of logical system of negation and its characterization in formalist mathematics	**Type of refutability or absurdity (Curry)**	**Type of justificationism or falsificationism (Lakatos)**
LM (Minimal negation)	Simple refutability	Dogmatic falsificationism
LD (Strict negation)	Complete refutability	Naïve falsificationism
LE [Unspecified or variable]	Classical refutability	Sophisticated falsificationism
LK (Classical negation)	Complete absurdity	Justificationism
LJ (Intuitionalist negation)	Simple absurdity	Neo-justificationism

Table 4. Systems of Negation in Formalist Mathematics and Their Concordance with Lakatos's Methodologies.

Formalist mathematics had defined a limited set of relationships among some of these systems of negation. Figure 1 shows these systems as rectangles labelled with the names that Lakatos gave to the methodologies associated with those systems of negation. (For the latter, see Table 4.) The relationships established by formalist mathematics are depicted in Figure 1 as clear hexagons and arrows having clear triangular arrowheads, between the systems of negation depicted as rectangles. Lakatos did not augment the number of systems of negation he found in formalist mathematics, but through his study of empirical scientific method he implicitly added new definitions of relationships among them. Figure 1 includes a condensed and graphical exegesis of his work, presented here for the first time. The relationships added by Lakatos are shown in Figure 1 as cross-hatched hexagons and arrows having solid triangular arrowheads. However, Lakatos

failed to consider the consequences of his implicit classification of relationships among these epistemologies.

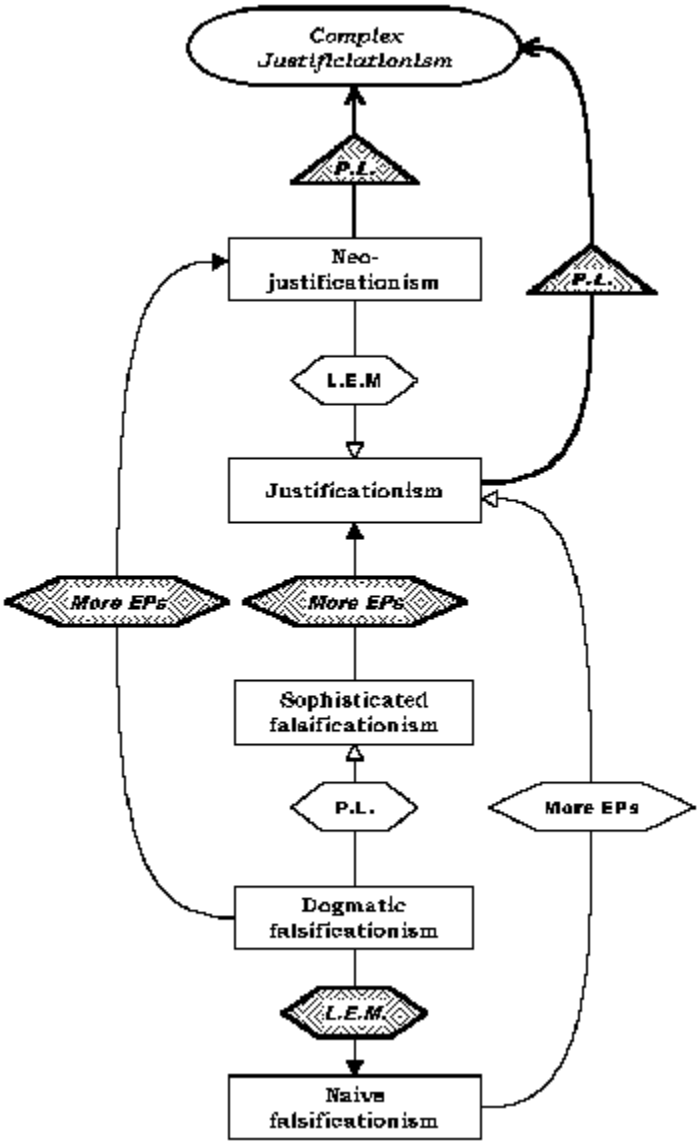

Figure 1. Complex Justificationism and Its Logico-Mathematical Relations to Other Systems of Negation.

Formalist mathematics had employed two devices to define only limited relations among only some systems of negation: the Law of Excluded Middle (LEM in Figure 1) and the multiplication of elementary propositions (EPs in Figure 1). Lakatos defined relationships, not derived from formalist logic, between naïve falsificationism and justificationism, between neo-justificationism and justificationism, and between sophisticated falsificationism and dogmatic falsificationism. To motivate the last of these new relationships, he introduced the use of Peirce's Law (PL in Figure 1). Peirce's Law is a form of denial of the law of excluded middle. It asserts that in a Venn diagram with intersecting circles A and B, the intersection of A with that part of B lying outside A, is the arc of circle A that is inside circle B. Subtracting the arc of A identified under Peirce's Law from A-intersection-B (the complement of only-A in B) then produces what is called the pseudocomplement of A. The pseudocomplement of a lattice is analogously the interior of its complement. This is important for what follows below.

In Figure 1, the order of the methodologies, from naïve falsificationism at the bottom to neo-justificationism near the top, has been established according to the lesser or greater amount of theoretical content that the different methods generate. Thus naïve falsificationism generates the least amount of theoretical content, and neo-justificationism the most. Complex justificationism is arbitrarily placed hierarchically above neo-justificationism, but the typology of the Figure 1 gives no indication in fact whether its theoretical content is greater than that of any of the others. Indeed, this almost certainly varies with the empirical case studied.

Excluding complex justificationism for the moment (and the arrows ending on it), the figure representing relations among the other five, including the arrows between the systems of negation, is a mathematical object called a classical implicative lattice. Such a lattice, as a mathematical object, has what is called a pseudocomplement, which is the interior of its complement analogous to the definition just given in connection with Peirce's Law.

The counteraxioms of an emergent successor research program are the content of that pseudocomplement. Their coalescence as a pseudocomplement and their consolidation as a set of counteraxioms, rather than as a series of *ad hoc* hypotheses, cracks the "hard core" of an antecedent research program despite the attempt of its "protective belt" to absorb the blows. When such a construction is placed upon the development from a neo-justificationist methodology, through the "adjoinment" of Peirce's Law to it, the resulting mathematical object is what is called an implicative semilattice. (A semilattice is a representation of a partially ordered set.) The full Figure 1 is an implicative semilattice.

All these systems of negation are constructed from elementary propositions. Such

elementary propositions may be singular or multiple, and the systems themselves may be single, multiple or mixed. These are definitionally distinguished as follows. A singular system is one in which all elementary propositions are required to be singular. A multiple system is one in which there is no restriction in the rules requiring an elementary statement to be singular. A mixed system is one in which there are no such restrictions for the system as a whole, but there are such restrictions on the applicability of certain rules.

A sophisticated-falsificationist research program is a mixed system. That is because Lakatos's "sophisticated falsificationism" allows, indeed it mandates, the multiplication of hypotheses within the protective belt, but it restricts the application of this procedure to the protective belt. By contrast, all elementary propositions in the hard core are required to remain singular, indeed immutable. That is why Lakatos omits any discussion of exactly how a research program's protective belt changes even in research programs that are theoretically and empirically progressive.

In fact, any alteration of the protective belt necessarily entails alteration of the hard core. Lakatos did not see this because he split them from one another. He had first referred to them as the "positive heuristic" and "negative heuristic," implicitly acknowledging that together they constituted a single entity. He split them as he did, because he wanted to make intuitionistic mathematical logic operational within a neo-Popperian epistemological framework. That is what "sophisticated falsificationism" appeared to accomplish.

However, logics informed by intuitionistic schools of mathematics do not require that elementary propositions be singular. Lakatos's failure to address how research programs succeed one another is a consequence of his absolutizing the artificial distinction between a "positive" and a "negative" heuristic. As antidote to this fallacy, the device of a "macrotheory" was introduced in the above case study as a medium through which changes may be transmitted from one to the other. The case study given here, shows how this manner of proceeding clarifies the way in which propositions in the protective belt are consolidated into a revised heuristic. The result of this demonstration is to overturn sophisticated falsificationism as a methodology of research programs.

What Lakatos thus failed to see in particular was that the application of Peirce's Law (as following from generalization based upon empirical experimental work) permits the emergence of a new heuristic as a matter of scale. If not all elementary propositions in the old heuristic are singular, then their evolution may take shape as the consolidation of a new heuristic. That is how such emergence occurs. When translated into the language of formalist mathematics, this failure is expressed by saying that Lakatos requires the

exclusion of formalizable epitheoretical arguments, even though (and especially although) these may well represent counteraxioms that themselves form the basis of a new research program. This failure equally explains why Lakatos does not systematically address the dynamic that drives movement from one research program to another.

Lakatos's vehicle for arriving at sophisticated falsificationism was to adjoin Peirce's Law to dogmatic falsificationism. For the purpose of conceptualization, dogmatic falsificationism may be considered as creating a space of "provable" scientific theories on the basis of the elementary propositions constituting its system of negation. If we turn this analogy into a metaphor, we may say that adjoining Peirce's Law to that basis produces new spaces containing previously inconceivable provable theories.

But Lakatos does not ask what happens if we adjoin Peirce's Law to either justificationism or neo-justificationism. Such an operation is depicted by the cross-hatched triangles in Figure 1, with their arrows having pronged arrowheads. The result, in fact, is to reveal an entirely new, sixth system of negation that exactly expresses the logic of a complexity-science methodology. It is depicted in Figure 1 by the oval shape. In this article, the new system of negation has been denoted as "complex justificationism." As explained above, the succession of research programs in the Western theory and study of domestic politics of Soviet foreign policy making illustrates such a progression from one research program to another according to the tenets of complexity science. It exemplifies how the abolition of Lakatos's artificial distinction between negative and positive heuristics is achieved through recognition of the emergence of a set of counteraxioms forming the basis of a new research program. The present Appendix has given expression to such a procedure in terms proper to mathematical logic.