A natural extension of the methodology of the scientific research programmes of Imre Lakatos

Nicolae Sfetcu

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Email: nicolae@sfetcu.com

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Both general relativity and quantum mechanics are paradigms in Kuhn's sense[1]. Both coexist simultaneously. But in Kuhn's scheme there is no such situation in which two simultaneous paradigms coexist peacefully. Kuhn's paradigm is defined primarily from a sociological point of view[2]. In this sense, the "family" of relativists coexist peacefully with the "family" of quantum physics theorists for almost a hundred years, without much interaction between them. In universities, both paradigms are accepted. Both paradigms also have a common feature: the claim for completitude and universality Quantum theoreticians consider that the role of the observer and the corresponding statistical interpretation are properly described only in the framework of quantum theory. At the same time, the supporters of the theory of general relativity consider that gravitational interaction is universal and must be represented by curved, geometric space-time, which in turn influences gravity.

The two above paradigms are essentially incompatible from the point of view of the observational system[3]. Despite the incompatibility, the two paradigms are traditionally applied in different fields, namely macrophysics and microphysics. Both paradigms do not present decisive anomalies and are extremely efficient and respected. Also, there is no competition between the two paradigms. It turns out that *this contemporary situation in physics is not compatible with Kuhn's scheme for the structure of scientific revolutions*.

Lakatos proposed a methodology for investigating the evolution of science through research programs, a combination of Popper's falsifiability, Kuhn's scientific revolutions and Feyerabend's methodological tolerance[4]. Lakatos' concept takes into account a series of theories included in a research program, in which each new theory results by the addition of auxiliary clauses (or semantic reinterpretations) of existing theories to explain some anomalies. Such a new theory is theoretically progressive if it has an excess of empirical content over existing theories (if it predicts new facts), and it is empirically progressive if some of these predictions are confirmed (it produces new facts). A new theory is progressive both theoretically and empirically, and otherwise

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[1] Thomas S. Kuhn, *The Structure of Scientific Revolutions*, 3rd edition (Chicago, IL: University of Chicago Press, 1996).

[2] Kuhn, 10.

[3] Jürgen Audretsch, „Quantum Gravity and the Structure of Scientific Revolutions", *Zeitschrift Für Allgemeine Wissenschaftstheorie* 12, nr. 2 (1 septembrie 1981): 322–39, https://doi.org/10.1007/BF01801202.

[4] Imre Lakatos, *The Methodology of Scientific Research Programmes: Volume 1: Philosophical Papers* (Cambridge University Press, 1980).

degenerate. It is considered "scientific" if it is at least theoretically progressive. A theory in the series is "falsified" when it is replaced by a theory with more corroborated content.

There is no time limit for the final evaluation of a program; so, this program obbeys to neither Popper's "refutation" nor Kuhn's "crises". A new research program (a new scientific concept, for example) benefits from a certain methodological tolerance. "Crucial" experiments can be considered decisive "after a long retrospective" only. As Lakatos states, “the discovery of an inconsistency - or of an anomaly - must *immediately* stop the development of a programme: it may be rational to put the incon sistency into some temporary, *ad hoc* quarantine, and carry on with the positive heuristic of the programme." Thus, Kepler's ellipses were admitted as crucial evidence for Newton and against Descartes one hundred years after Newton's *Principle*[5]. And the abnormal behavior of Mercury's perihelion has been known for decades as an anomaly in Newton's program, but only the development of Einstein's theory has transformed it into a "refutation" of Newton's research program.

For Lakatos, the history of science is a history of competing research programs ("paradigms"), but does not necessarily include Kuhnian periods of normal science, allowing the simultaneous coexistence of competing theories even if the new theory has, for a period of time that may take tens for years, a lower heuristic power.

Heuristics is a central concept of Lakatos philosophy. It tells us which research paths to avoid (negative heuristics) and which paths to follow (positive heuristics), giving a definition of the "conceptual framework" (and, consequently, language). The negative heuristic forbids us to point *modus tollens* to the "hard core" of the program. With the help of positive heuristics, you can articulate or even invent "auxiliary hypotheses" that form a protective belt around this nucleus, which must withstand tests and be adjusted, or even completely replaced, to defend the nucleus.

While theoretical progress (as described by Lakatos) may be immediate, empirical progress may not be verified for long time, and a long series of "refutations" may occur in a research program before the auxiliary hypotheses in growth, with appropriate content, or revising false "facts," to turn the program into a success story. The positive heuristic ignores the real examples, the "available" data, based on the "models" predetermined by the researchers withn the research program, which can be modified and even replaced in the further development of the program. In

[5] Isaac Newton, „Philosophiæ Naturalis Principia Mathematica, I Ed.”, The British Library, 1687, https://www.bl.uk/collection-items/newtons-principia-mathematica.

this evolution, the "refutations" are irrelevant, being predictable and overcome by the research strategy.

According to Lakatos, "This methodology offers a new rational reconstruction of science. It is best presented by contrasting it with falsificationism and conventionalism." [6] The history of science is, in Lakatos's opinion, the history of research programs rather than theories, which is a partial justification for the idea that the history of science is the history of conceptual frameworks or scientific language. . "A program advances theoretically if the new theory resolves the anomaly and is independently verifiable by making new predictions, and it advances empirically if at least one of these new predictions is confirmed. A program can progress, both theoretically and empirically, even if every theory produced within it is rejected. A program degenerates if its successive theories are not theoretically progressive (because they do not predict new facts) or are not empirically progressive (because new predictions are rejected)." [7]

The models within the research programs are sets of idealized conditions but increasingly closer to the reality, and possibly observational theories, used during the program to help its development. The refutation of these models is foreseen within the development strategy (positive heuristics), being irrelevant and "digested" by the next model. Thus, the difficulties of a program are rather mathematical than empirical. The refutations of the models are rather checkings (corroborations) of the approximation of the model to the reality, and of its heuristic power. According to the methodology, the first models are so idealized that it may not correspond to reality at all.

According to Barry Gholson and Peter Barker, Lakatos' methodology suggests that research programs evolve from an initial state that resembles to instrumentalism, to a mature state that resembles to realism. In particular, in Newton's research program, Lakatos states that the first theory in a program was be so idealized that it represents nothing (the distinguishing sign of instrumentalism) [8]. Replacing the theory with new successive theories as the program progresses, he changes the initial model into an increasingly plausible candidate for reality. An important part of the heuristic program consists of recommendations for the incorporation of new features, absent in the initial theory, but which are necessary for real world representations. Thus, the

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[6] Lakatos, *The Methodology of Scientific Research Programmes*, 110.

[7] Nicolae Sfetcu, „Reconstructia Rationala a Stiintei Prin Programe de Cercetare" (2019), http://doi.org/10.13140/RG.2.2.24667.21288.

[8] Lakatos, *The Methodology of Scientific Research Programmes*, 50–51.

instrumentalist and realistic features of the Lakatos research program are incompatible with the mutually exclusive categories presented by the logical empiricists. [9]

Lakatos describes a research program as follows:

> "It consists of a developing series of theories. Moreover, this developing series has a structure. It has a tenacious hard core, like the three laws of motion and the law of gravitation in Newton's research programme, and it has a heuristic, which includes a set of problem-solving techniques... Finally, a research programme has a vast belt of auxiliary hypotheses on the basis of which we establish initial conditions... I call this belt a protective belt because it protects the hard core from refutations: anomalies are not taken as refutations of the hard core but of some hypothesis in the protective belt. Partly under empirical pressure (but partly planned according to its heuristic) the protective belt is constantly modified, increased, complicated, while the hard core remains intact." [10]

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[9] Barry Gholson și Peter Barker, „Kuhn, Lakatos, and Laudan: Applications in the history of physics and psychology”, *American Psychologist* 40, nr. 7 (1985): 755–69, https://doi.org/10.1037/0003-066X.40.7.755.

[10] Lakatos, *The Methodology of Scientific Research Programmes*, 179.

The natural extension of the Lakatos methodology

Research programs allow the development of more complex theories. Barry Gholson and Peter Barker believe that the terms can be applied to both individual theories and programs. If it is applied to the theories of a research program, I consider that they in turn become research programs, which we can call *research subprograms*.[11]

Unlike Kuhn's scientific revolutions, Lakatos assumed that the simultaneous existence of several research programs is the norm. Science is currently facing such an unusual situation: two incompatible theories, but both accepted by the scientific community describe the same reality in two different ways. Quantum mechanics governs phenomena at small dimensions of elementary particle physics, at speeds much lower than the speed of light and high energies, and general relativity deals with the macro universe, at speeds close to the speed of light and small energies. Thus, a problem of underdetermination in physics appeared. The quantum gravity attempts to complete the scientific revolution in physics started in the 19th century, for the unification of all fundamental forces, by merging the two frameworks of quantum physics and general relativity. From the efforts of physicists in this attempt resulted a rich variety of approaches, techniques and theories, of which the most known are string theory and loop quantum gravity. But the evolution in this direction is very slow and littered with many uncertainties and disputes.

The problem of underdetermination implies that more than one theory is compatible with empirical data. Underdetermination may be relative to the currently available data (transient, or scientific underdetermination), in which case theories may differ in unverified predictions, or underdetermination between theories or theoretical formulations regarding all possible data (a "permanent underdetermination"), when all their predictions are identical. A permanent underdetermination disappears (it does not have a real significance) in the case of the instrumentalist approach if the theories are individualized only in terms of their empirical content. But if we assume that the formulations of alternative theories describe different scenarios, the underdetermination must be considered real.

Quine states that two logically incompatible theories can be both compatible with the data but, if there is a mapping between the theoretical formulations, they do not in fact describe different theories, they are different variants of the same theory ("reconstruction of predicates"). Matsubara states that the formulations can represent two true alternative theories despite the structural

[11] Gholson și Barker, „Kuhn, Lakatos, and Laudan”.

similarity, as there are relevant semantic differences that are lost in mapping of the logically or mathematically formalized theory.

Research programs may at one time compete with single theories, single theories between them, or research programs between them. We can speak of a "*research unit*" as a singular theory or a research program.

Bifurcated programs

Barry Gholson and Peter Barker state that Lakatos' basic methodology is not an effective way to represent the underlying metaphysics identified by Kuhnians and Popperians, due to the simultaneous existence of several Lakatos-type theories that exemplify the same set of fundamental commitments. According to them, the research program consists of a series of successive theories that form chains, but never groups or families of linked theories that can compete.

It is a wrong statement, in my opinion. Lakatos has never denied such sequences. Moreover, such a group theory, called by these "clusters", can naturally develop within Lakatos' methodology. Later, Laudan developed this idea of a series of theoretical chains included in a single historical entity determined by the dominance of a certain set of metaphysical commitments. In some cases, contradictory theories can be developed based on the same basic commitments.

Lakatos' methodology does not exclude these situations; even more, they can result in a very natural way, if we consider that such theories start from the same hard core (same negative heuristic) but using a different development strategy (positive heuristic). I call these theories "*bifurcations*", respectively *bifurcated theories* or even *bifurcated programs* within a long-term approach.

Lakatos himself notes that a research program can be bifurcated at a given moment:

> "But one should not forget that *two specific theories, while being mathematically (and observationally) equivalent, may still be embedded into different rival research programmes, and the power of the positive heuristic of these programmes may well be different*. This point has been overlooked by proposers of such equivalence proofs (a good example is the equivalence proof between Schrodinger's and Heisenberg's approach to quantum physics)."

Unifying programs

Immediately after 1900, Planck's quantification questioned all classical physics. Until then, physics had developed through the application, extension, modification or reinterpretation of established physical theories, in a one-dimensional chain. But physics - especially Newtonian mechanics and Maxwell-Lorentzian electrodynamics - were no longer valid according to Planck's results. A new theory was needed, but that could no longer be obtained from the extension or modification of the existing physical theories, because they seemed to be fundamentally wrong. Thus, Einstein was forced to invent a new fundamental theory, trying to unify the current theories. This is how special relativity appeared, out of necessity.

Subsequently, the unification of all forces, through a quantum approach of the general relativity, became the main concern of quantum gravity. There are precedents in this regard: from classical electromagnetic theory and classical mechanics, two new independent unifying theories have emerged, special relativity and quantum mechanics; from special relativity and quantum mechanics the quantum field theory resulted; and at present it is hoped to arrive at a new unifying theory, from general relativity (a generalization of special relativity) and quantum field theory. These unified theories combine the theories from which they formed into a new common framework.

Within the Lakatos methodology, about these *unifying theories* it can be stated that they belong to a new research program with negative and positive heuristics different from those of the *unified research programs*, but the corresponding theory is reduced to the *unified theories* under certain conditions. I call such a program a "*unifying program*" ("*unifier*"), resulted within the concept of unification.

To be accepted, a unifying program must have a greater heuristic (theoretical or experimental) power than its unified programs.

Thus, the string theory attempts to unify the general theory of Einstein's relativity with quantum mechanics, in a way in which the explicit connection with both quantum theory and the reduced energy description of space-time in general relativity is maintained. At low energies, it naturally gives rise to general relativity, gauge theories, scalar fields and chiral fermions. String theory incorporates several ideas that do not yet have experimental evidence, but which would allow the theory to be considered a unifying candidate for physics beyond the standard model.

Matsubara appreciates Lakatos' methodology in Hacking's interpretation, but he also notes the lack of a fusion of different research programs in Lakatos's methodology, giving as examples of unified theories Schrodinger's wave mechanics and Heisenberg's matrix mechanics. He also considers the possibility of a fusion of ideas from string theory and some of its competitors, such as loop quantum gravity.

Due to the complexity and the wide variety of phenomena at the cosmological level, scientists build models based on individualized research programs, depending on the specific phenomenon (specific to black holes, for example), taking as the hard core of these programs the principles of general relativity or quantum mechanics. Subsequently, these research programs are trying to unify within some research programs such as black holes, or even larger ones, for gravitational or space-time singularities. For each phenomenon there are several alternative research programs, finally gaining recognition only those that have a higher heuristic power, but often there are smaller groups of researchers who do not give up even the alternatives with a lower heuristic power.

The unifying research programs can be developed simultaneously with the programs that will be unified (and in this case we can speak of the unified programs as "*research subprograms*"), or later, choosing from several programs the ones that best fit with the unifying program. This is a widely used way in recent years. When a concept evolves over a long time through independent research programs, without a unifying program to include them, we are not talking about a methodology of a certain research program, but a *rational reconstruction* of the science to which these independent programs compet.

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