Heuristics of Newtonian Gravity

Nicolae Sfetcu

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Email: nicolae@sfetcu.com

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The classic example of a successful research program is Newton's gravitational theory, probably the most successful Lakatosian research program. Initially, Newton's gravitational theory faced a lot of "anomalies" ("counterexamples") and contradicted the observational theories that supported these anomalies. But supporters of the Newtonian gravity research program have turned every anomaly into corroborating cases. Moreover, they themselves pointed to counterexamples which they then explained through Newtonian theory[1]. According to Lakatos, "In Newton's programme the negative heuristic bids us to divert the *modus tollens* from Newton's three laws of dynamics and his law of gravitation. This 'core' is 'irref utable' by the methodological decision of its proponents: anomalies must lead to changes only in the 'protective' belt of auxiliary, 'observational ' hypotheses and initial conditions." [2]

Newton established the positive heuristic of his research program through a strategy of successive approaches[3]. Newton's first three laws of motion regulated inductive reasoning, along with Newton's view of a fundamental taxonomy based on physical forces (interactions). It started from an idealized solar system, with a punctual Sun and a single planet circling around the Sun. Then he considered that the orbit of the planet is an ellipse, deriving the proportionality between the gravitational force and the inverse of the square of the distance between the planet and the Sun.

The inductive generalization of Newton considered an elementary motion with a static force included in the deduced law of gravity, and the idea that planetary movements can be generalized. These were his working hypotheses on the basis of which he proceeded to his inductive generalizations. They offer immediate protection of the hard core of the Newtonian research program (negative heuristics), by requiring that the evidence developed from the data be of high quality[4]. The deduction of the law of gravity fulfilled this requirement to a greater extent than its demonstrative reasoning, but the "deduction" was primarily based on the motion of only five planets in a short astronomical period.

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[1] Pierre-Simon Marquis De Laplace, *Exposition du systéme du monde*, 2nd ed. (Cambridge; 2009: Cambridge University Press, 2009).

[2] Imre Lakatos, *The Methodology of Scientific Research Programmes: Volume 1: Philosophical Papers* (Cambridge University Press, 1980), 48.

[3] Imre Lakatos, "Criticism and the Methodology of Scientific Research Programmes," *Proceedings of the Aristotelian Society* 69, no. 1 (1968): 149–186.

[4] I. Bernard Cohen and George E. Smith, *The Cambridge Companion to Newton* (Cambridge University Press, 2006).

Newton acknowledges the risk of introducing such taxonomic working hypotheses into inductive generalization, in the most famous methodological passage in *Opticks*, in discussing the "analysis and synthesis" methods in the next paragraph of the final query, which was added in 1706. He has considered that the success obtained from unrestricted generalizations is the best protection against the risk introduced by the inevitable taxonomic hypotheses that enter into induction. [5]

This model contradicted the law of action and reaction that Newton included in the hard core, so he developed a more complex model, in which the sun and the planet revolved around their center of common weight. It did not generate any anomaly, but it was difficult to deduce from it the real laws of motion for several bodies. Thus, Newton developed a new theory, for several planets, with interactions between each planet and the Sun but neglecting the interactions between planets.

After the intermediate verification of this theory, Newton developed a more complex theory, considering that the Sun and the planets are not punctual, but spheres with dimensions other than zero, since in theory he had to take into account the density of bodies, and could not accept that a point body has infinite density. He also took into account the rotational motion of the bodies around their own axes. In the following model it took into account the non-spherical shape of the Earth and the variation of the gravity of the surface with the latitude, the orbit of the Moon, the tides, the precession of the equinoxes and the trajectories of comets. Through this positive heuristic he tried to protect himself against the risks that appear in the inductive leap, immediately pushing the theory to analyze all relevant phenomena, and using it as a research tool for the problems encountered[6]. At the same time, the deductions in the case of the Earth allowed him to generalize from the celestial gravity to the universal gravity, as well as the precession of the equinoxes indirectly, taking into account the forces (interactions) between the planets, calculating the resulting perturbations. The tide and the precession of the equinoxes allowed the generalization from simple centripetal forces to an interactive gravity, as did the study of the orbits of Jupiter and Saturn. And the study of comets has allowed the extension of the law of gravity to bodies possible from a very different matter.

He published the results of his research program only when he considered that he had obtained as much as possible from observations and mathematics. The process of comparison with phenomena and arguments for the universality of gravity extends throughout Book 3.

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[5] Cohen and Smith.

[6] Cohen and Smith.

Newton's inductive generalization for universal gravity introduced an important falsifiable conjectural element, which was subsequently verified, providing the most convincing evidence in his favor. The basic idea was that any discrepancy between Newtonian theory and observation would prove to be physically significant and would tell us something more about the physical world. By this, the taxonomic working hypotheses that underlie Newton's inductive step toward universal gravity remain intact, as theory advances.

Based on additional questionable assumptions, and suggestions regarding the movements of Jupiter and Saturn, Newton initiated his own sequence of successive approximations according to the *Principia*. Even after the third edition of the *Principia* appeared, almost forty years later, each of these *Principia* subjects was still being studied. Newton's argument for universal gravity was only completed a century after the publication of the first edition of the *Principia*.

Newton foresaw the further developments of his models from the first fully idealized model. He understood that the intermediate models would contain anomalies, but he had to go through them in order to develop the mathematical apparatus by confronting the models and modifying the theory along the way so as to eliminate the anomalies.

Newton asserted that *Principia* illustrated a new approach to empirical inquiry. But, besides the remark about the derivation of forces from the phenomena of movement and then of the movements of these forces in the Preface to the first edition, and the remark about comparing a generic mathematical theory of centripetal forces with phenomena to find out the conditions of action of the force, from the end Book 1, Section 11, the only notable remark about the methodology is the famous passage from the general Scholium added in the second edition as a final statement[7].

The unprecedented success of Newton's theory of gravity has stimulated interest in the methodology of *Principia* for use in other fields. Two aspects of the methodology are obvious to George Smith[8]: Newton has opposed his method to the "hidden" assumptions, and the requirement that questions be considered open as long as empirical considerations have not yet given them answers (a requirement in perfect agreement with tolerance methodology proposed by

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[7] George Smith, "Newton's Philosophiae Naturalis Principia Mathematica," in *The Stanford Encyclopedia of Philosophy*, ed. Edward N. Zalta, Winter 2008 (Metaphysics Research Lab, Stanford University, 2008), https://plato.stanford.edu/archives/win2008/entries/newton-principia/.

[8] Smith.

Lakatos in the research programs). The purpose of the method was to limit the theoretical claims to "inductive generalizations".

Each successive model in Newton's program predicts a new fact, it is an increase of the empirical content: it constitutes a consistent progressive theoretical change. And each prediction is finally verified, though previously it could have been instantly "refuted".

The central idea of the Newtonian inductive method is that universal laws inductively derive from the "manifest qualities" or "phenomena" observed, and only the observed phenomena can lead us to the revision of these laws. Newton explicitly opposes purely hypothetical explanations of mechanistic philosophy. Leibniz and Huygens accepted Newton's demonstration that the orbits of the satellites of the large astronomical bodies in the solar system obey the inverse-square law, but they rejected Newton's law of universal gravity because they were related to mechanistic philosophy. The rules III and IV of Newton were added to the second (1713) and third (1726) editions of the *Principia* in response to the objections of the mechanistic philosophers:

> Rule III: "Those qualities of bodies that cannot be intended and remitted [i.e. qualities that cannot be increased and diminished] and that belong to all bodies on which experiments can be made should be taken as qualities of all bodies universally." [9]
>
> Rule IV: "In experimental philosophy, propositions gathered from phenomena by induction should be considered either exactly or very nearly true notwithstanding any contrary hypotheses, until yet other phenomena make such propositions either more exact or liable to exceptions." [10]

These rules state that the inductive universalization method must be applied without interference of hypotheses. Newton explicitly states that the mechanistic philosophy assumptions obstruct his method. He illustrates here the use of his method by first describing the inductive inference of universal law that all bodies are extended.

Bernard Cohen thus describes Newton's positive heuristics, in Chapter 5 of The Cambridge Companion to Newton as the "Newtonian style" stages[11]: (1) the "one-body" problem, (2) the "two-body" problems, (3) the problems of three or more interacting bodies. Thus, Newton must

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[9] Isaac Newton, "Philosophiae Naturalis Principia Mathematica, III Ed.," *Science* 177, no. 4046 (1726): 795, https://doi.org/10.1126/science.177.4046.340.

[10] Newton, 796.

[11] Cohen and Smith, *The Cambridge Companion to Newton*.

approach the complexity of a real orbital motion in a succession of successive approximations, each approximation being an idealized movement, and with systematic deviations, providing evidence for the next stage of the sequence.

In his idealized models, Newton imposed two restrictions on successive approximations[12]. In each case in which he deduces some characteristics from the celestial gravitational forces, he argued that the consequence of the "if-then" deduction still maintains closeness as long as the antecedent has closeness. And the mathematical results established in Book 1 allow him to identify the specific conditions under which the phenomenon from which the deduction is made would have not only proximity, but also accuracy. It follows that Newton's "deductions" from phenomena involve trying to address the complexity of real-world movements in a sequence of increasingly complex progressive idealizations, with systematic deviations from idealizations, each model serving as the basis for the next more complex model. Systematic deviations are called "secondary phenomena" when they are not observable *per se*, but theoretically deduced[13]. This respects Newton's first rule for natural philosophy - that no more causes than both true and enough causes should be admitted explaining a phenomenon.

Newton's law of gravity provides an explanation of Kepler's rules and idealized orbital movements for each previously idealized model, so it has greater heuristic power than any previous model. By this law one can explain why these idealizations are valid at least in the proximity.

From the perspective of Lakatos, in the 17th century three scientific systems were in competition: the research program of Aristotle, that of Descartes, and Newton's program appeared as a rival of Descartes's program. Both Descartes and Newton's programs were progressive compared to Aristotle’s and could explain the movements of comets and tides. The Cartesians could explain why the moon always kept the same face to the ground and why all the planets rotate in the same direction, while the Newtonians could explain how the planets influence one another[14]. Explanatory differences resulted from different hard cores. The core of the Cartesian program specified contact action and explicitly forbade the concept of action at a distance.

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[12] Domenico Meli, “The Relativization of Centrifugal Force,” *Isis: A Journal of the History of Science* 81 (1990): 33.

[13] Cohen and Smith, *The Cambridge Companion to Newton*.

[14] E. J. Aiton, *Vortex Theory of Planetary Motions*, First Edition edition (London; New York: American Elsevier Publishing Co., Inc., 1972).

Newton's program also includes elements of the older Cartesian program, such as contact action. This is an example of a fruitful exchange between programs. But the empirical evidence ultimately led to the failure of the Cartesian program.

Lorentz's program reached a dominant position at the beginning of the 20th century, then being overtaken by Einstein's, both theoretically and empirically, almost immediately after its initiation in 1905[15]. Although Lorentz's program was also progressive, relativity's program overcame, being consistently more progressive and assimilating the Lorentz transformations. [16]

In the success of Einstein's program, several research programs were involved: the Newtonian program, caused by a program supported by Lorentz[17] that made electromagnetism accepted as more fundamental than mechanics; a second rival program supported by Ostwald and Mach through which an attempt was made to develop a purely phenomenological physics, with energy as a basic concept[18]; Einstein's program which involved the theories of relativity; and the program of quantum physics initiated by Bohr and developed by the theories of Heisenberg, Schrodinger and Dirac.

In the first two decades of the 20th century, quantum physics overcame the phenomenological program and replaced Newtonian physics, but the mathematics and ontology of the new program were incompatible with the mathematics and ontology of Einstein's program. However, these programs coexist today. The rivalry between these programs stagnated in the 1940s and 1950s, reviving with the advent of radio astronomy, which allowed new empirical progress.

Lakatos' methodology offers a powerful conceptual framework, which, as in Kuhn's case, derives from the analysis of historical episodes in physics. But unlike Kuhn, Lakatos presented a

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[15] Elie Zahar, “Why Did Einstein’s Programme Supersede Lorentz’s? (II),” *British Journal for the Philosophy of Science* 24, no. 3 (1973): 211–75.

[16] Barry Gholson and Peter Barker, “Kuhn, Lakatos, and Laudan: Applications in the History of Physics and Psychology,” *American Psychologist* 40, no. 7 (1985): 755–69, https://doi.org/10.1037/0003-066X.40.7.755.

[17] Zahar, “Why Did Einstein’s Programme Supersede Lorentz’s?”

[18] Niles Holt, “Wilhelm Ostwald’s ‘The Bridge,’” *British Journal for the History of Science* 10, no. 2 (1977): 146–150.

methodology that avoids the problems of incommensurability[19] and irrationalism and demonstrates that empirical evidence is the ultimate arbiter of competing research programs. [20]

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[19] Two theories are incommensurable if they are embedded in a strongly contrasting conceptual framework, whose languages do not overlap enough to allow scientists to directly compare theories or to cite empirical evidence favoring one theory over the other.

[20] Gholson and Barker, “Kuhn, Lakatos, and Laudan.”

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