Newton's Abductive Methodology

A Critique on Duhem, Feyerabend, and Lakatos

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Introduction

Sir Isaac Newton is considered to be the flagbearer of promoting the *inductive method*.

With his *Principia* he put forward a framework which marked the route of physics for more than two centuries both in theoretical as well as methodological respect.

However, modern philosophy of science theorising about Newton's methodology and actual procedure states that he did not "practice what he preached".

This talk is about Newton's "walk the talk".

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Newton's Methodology

Sources

- *Philosophiæ Naturalis Principia Mathematica*, particularly:
  - Preface to the first edition (cf. Newton 1726(E3)/1999, pp.381–383)
  - Cotes' preface to the second edition (cf. Newton 1726(E3)/1999, pp.385–399)
  - *Scholium* in Book 1, Section 11 (cf. Smith 2002, p.140; and Newton 1726(E3)/1999, pp.588f)
  - *Regulæ Philosophandi* (Rules of natural science, cf. Newton 1726(E3)/1999, pp.794–796 (Book 3))
  - *Scholium Generale* (cf. Newton 1726(E3)/1999, pp.939–945 (Book 3))
- *Opticks: Or, a Treatise of the Reflections, Refractions, Inflections and Colours of Light* (cf. Newton 1721), particularly:
  - Query 31 (cf. Newton 1721, p.380 (Book 3))
- Correspondence, particularly:
  - Correspondence with Henry Oldenburg (cf. Lakatos 1980, p.218; and Feyerabend 1978, p.206)

Newton's Research Programme

Theoretical Part

In the terminology of Imre Lakatos' scientific research programmes, the Newtonian programme of the *Principia* consists of:

Core: Three general axioms on forces:

Law 1: "Every body perseveres in its state of being at rest or of moving uniformly straight forward, except insofar as it is compelled to change its state by forces impressed":

$$\forall x, t : \sum_{i \in S} f_i(x, t) = 0 \Rightarrow a(x, t) = 0$$

Law 2: "A change in motion is proportional to the motive force impressed and takes place along the straight line in which that force is impressed":

$$\forall x, t : \sum_{i \in S} f_i(x, t) = m(x) \cdot a(x, t)$$

Law 3: "To any action there is always an opposite and equal reaction;":

$$\forall x, t \forall i \in S \exists j \in S : f_i(x, t) = -f_j(x, t)$$

Periphery: Further axioms about specific forces etc.:

Law G: "Gravity exists in all bodies universally and is proportional to the quantity of matter in each. [...] The gravitation toward each [...] body is inversely as the square of the distance of places from those [bodies].":

$$\forall x, y, t : f_g(x, y, t) = G \cdot \frac{m(x) \cdot m(y)}{d(x, y, t)^2}$$

Newton's Research Programme

Methodological Part: Editions

The methodological part of the programme was stepwise expanded:

- E1: First Edition of the *Principia* (1687, published with support by Edmond Halley)
- E2: Second Edition of the *Principia* (1713, edited by Roger Cotes)
- E3: Third Edition of the *Principia* (1726, edited by Henry Pemberton)

Newton proposes 4/5 *methodological rules* (*regulæ*). They appear in the *Principia* starting with edition E2 and E3;

Regulæ I–III appear in E2.

In E3 *regula IV* is added; and a further rule, *Regula V*, appears only in the manuscript of E3, but not in print.

Newton's Research Programme

Methodological Part: *Regulæ Philosophandi*

Regulæ I–IV (cf. Newton 1726(E3)/1999, pp.794–796):

I. "No more causes of natural things should be admitted than are both true and sufficient to explain their phenomena."

II. "Therefore, the causes assigned to natural effects of the same kind must be, so far as possible, the same."

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."

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."

Newton's Research Programme

Methodological Part: *Regulæ Philosophandi*

The last rule which is present only in the manuscript of E3 is (cf. Koyré 1965, p.272):

- V "Whatever is not derived from things themselves, whether by the external senses or by the sensation of internal thoughts, is to be taken for a hypothesis. Thus I sense that I am thinking, which could not happen unless at the same time I were to sense that I am. But I do not sense that any idea whatever may be innate. And I do not take for a phenomenon only that which is made known to us by the five external senses, but also that which we contemplate in our minds when thinking: such as, I am, I believe, I understand, I remember, I think, I wish, I am unwilling, I am thirsty, I am hungry, I rejoice, I suffer, etc. And those things which neither can be demonstrated from the phenomenon nor follow from it by the argument of induction, I hold as hypotheses."

Interpretation of *Regulæ* I & II

Regulæ I & II are usually interpreted as parsimony principles.
Epistemic rationale (cf. Forster and Sober 1994, sect.4): Assume X is to be explained causally (by help of probabilities Pr):

$Pr(X\|\cdot)$	C_1	$\sim C_1$
C_2	$c_0, c_1, c_2, c_{1,2}$	c_0, c_2
$\sim C_2$	c_0, c_1	c_0

The c_is are the parameters of the models. There are several options:

1. $Pr(X|C_1, C_2) = c_0 + c_1 \cdot val(C_1)$ (single cause)
2. $Pr(X|C_1, C_2) = c_0 + c_1 \cdot val(C_1) + c_2 \cdot val(C_2)$ (non-interactive causes)
3. $Pr(X|C_1, C_2) = c_0 + c_1 \cdot val(C_1) + c_2 \cdot val(C_2) + i_{c_1,c_2} \cdot val(C_1) \cdot val(C_2)$ (interactive causes)

By employing reasoning of model selection:

- Accuracy (better in 3>2>1) $\Rightarrow$ on average more fitting of errors in data, i.e. overfitting.
- Simplicity (better in 1>2>3) $\Rightarrow$ on average less fitting of errors in data.

One needs to balance accuracy and simplicity.
In the line of Newton: $\text{accuracy}_1 = \text{accuracy}_2 \Rightarrow$ opt for the simpler model.

Interpretation of *Regulæ* IV & V

Regulæ IV & V are usually interpreted programmatically.

It is clear that particularly *regula V* is directed against Cartesians (vortex theory).

These rules are intended to license inductive inference and shield it against *a priori* rationalistic theorising (cf. also: "*Hypotheses non fingo*").

(Why did Newton not take in *regula V* in the printed version of E3? Conjecture of Koyré (1965, p.272): He did not want to include anti-Cartesian polemic in a scientific text.)

How is induction and its role to be understood? $\Rightarrow$ Newton's Method

Newton's Method: *Analysis and Synthesis*

. . . prominently called this way by Duhem (1954, p.190). Newton:

> *"The basic problem of philosophy seems to be to discover the forces of nature from the phenomena of motions and then to demonstrate the other phenomena from these forces." (Newton 1726(E3)/1999, Preface to the first edition, p.382)*

And:

> *"Analysis consists in making Experiments and Observations, and in drawing general Conclusions from them by Induction, and admitting of no Objections against the Conclusions, but such as are taken from Experiments, or other certain Truths. For Hypotheses are not to be regarded in experimental Philosophy. [. . .] By this way of Analysis we may proceed from [. . .] Effects to their Causes. [. . .] The Synthesis consists in assuming the Causes discover'd, and establish'd as Principles, and by them explaining the Phaenomena proceeding from them, and proving the Explanations." (cf. Newton 1721, Query 31, p.380)*

Interpretation of Newton's Method

Differs from hypothetico-deductivism: Not any hypothesis is admissible.

Schema of the method according to Hintikka and Remes (1974, p.110):

[*Analysis:*]

(i) an analysis of a certain situation into its ingredients and factors
$\rightarrow$
(ii) an examination of the interdependencies between these factors
$\rightarrow$
(iii) a generalization of the relationships so discovered to all similar situations
$\rightarrow$

[*Synthesis:*]

(iv) deductive applications of these general laws to explain and to predict other situations.

Induction in a narrow sense occurs only as step (iii).

Step (i) and (ii) are abductive ones.

Interpretation of Newton's Method: Abduction

Newton's proposal to theorise from "effect to the causes" is dealt within approaches to common cause abduction.

Rough idea (cf. Feldbacher-Escamilla and Gebharter 2019; Schurz 2008):

- A correlation among empirical phenomena is observed.
- Probabilistically speaking, this correlation can be explained by assuming a common cause.
- This kind of explanation is also to be preferred against other kinds of explanation (with different structures: common effect, common cause with intermediate causes, etc.), because it allows for unification.
- Unification can be epistemically justified again by the aim of avoiding overfitting (cf. Forster and Sober 1994, sect.3).

A Taxonomy of Interpretations of Newton's Method

Taxonomies of elements of *Newton's method* and their relations:

Newton	*Analysis*			*Synthesis*
	Decomposition			*Recomposition*
	Regulæ I & II		*Regulæ III & IV*	logic, geometry, *calculus*, etc.
Hintikka et al.	factor analysis (i)	dependency analysis (ii)	generalisation (iii)	deductive application (iv)
Duhem et al.	induction in the wide sense			deductive application
Example	Kepler's laws ⇒ Newton's laws (e.g. law of gravitation)			Newton's laws ⇒ description of the moon's orbit
Modern	general: data analysis with methodological norm: parsimony (cf. Forster and Sober 1994)	e.g. Bayes net analysis with causal relations (cf. Pearl 2000)	e.g. inductive generalisation in the narrow sense ("inductive logic")	deductive methods (logic, mathematics)

abduction

Critique on Newton's Actual Procedure

The Inconsistency-Critique on Newton

Rational reconstruction of Newton's theorising and his methodological suggestions led to hard critique.

Also studying the different editions (E1,E2,E3) suggests that he added the *regulæ post constructione* in order to "push" his programme.

Main critique: Newton did not comply with his own standards:

> *"The principle of universal gravity, very far from being derivable by generalization and induction from the observational laws of Kepler, formally contradicts these laws. If Newton's theory is correct, Kepler's laws are necessarily false. (cf. Duhem 1954, p.193)*

Similar claims can be found in: Lakatos (1980, p.213), Feyerabend (1981, p.174, 175, 206), and Popper (1983, p.140).

The Inconsistency-Critique on Newton

Argument:

1. Kepler's laws are, conditional on the at Newton's time accepted auxiliary assumptions, in contradiction to the observed orbits of the planets.
2. Newton's theory of motion in the solar system was and is quite accurate.
3. Hence: Kepler's and Newton's theory are incompatible. (from 1, 2)
4. Hence: Newton could not came up with his theory inductively on the basis of Kepler's laws. (from 3)

Note that in order to be valid, the argument needs a further premise:

Principle on the Relation Induction-Deduction (PRID)

If H is inductively inferred from E, then E can be deduced from H (plus auxiliary assumptions) or E is at least not incompatible with H.

So, did Newton not [theoretically] walk his [methodological] talk?

Rationalisation of Newton's Actual Procedure

Resolving the Inconsistency I

Restricted Domain of Analysis

An important approach in the literature reconciles Newton's theorising with his methodological proposal by restricting the basis of analysis.

The basis, *Kepler's laws*, is restricted to instances compatible with the result of analysis, namely Newton's theory (cf. Smith 2002; Ducheyne 2012):

> *"On closer scrutiny, the so-called contradiction [...] is simply non-existent – as any reader of the first three propositions of Book I and Phenomena I–VI as stated in Book III of the Principia can testify. The particular criticism raised is beside the point, as Newton demonstrated that exact Keplerian motion occurs only in one-body systems and that, under specific configurations, Keplerian motion occurs as most closely as possible (quam proxime) in three- and many-body systems as well. [...] There is no formal contradiction involved whatsoever."*
> *(cf. Ducheyne 2012, p.XV)*

Resolving the Inconsistency I

Restricted Domain of Analysis

Schema:

- Basis: three laws of Kepler: X
- Restriction for analysis to one-body systems: X'
- *Analysis*, applied to X', with inductive generalisation and the results of the first book of the *Principia*: Y
- *Synthesis*: Deduction of X' and further phenomena from Y (cf. Phänomen 4 in Newton 1726(E3)/1999, p.800)

Since in the restricted domain (one-body systems) X' is compatible with Y—X' is even a consequence of Y—, the principle on the relation between induction and deduction (PRID) is satisfied.

There is a further route to resolve inconsistency: argue against (PRID)

Resolving the Inconsistency II

Invalidity of (PRID)

(PRID) has two components:

1. $E \mid\!\sim H \quad \Rightarrow \quad H \vdash E$ (where $\mid\!\sim$ stands for an inductive inference)
2. $E \mid\!\sim H \quad \Rightarrow \quad H \nvdash \neg E$

Only 2 (follows from 1) is needed for validity of argument against Newton;

However, upholding only 2 seems to be too weak: If H follows inductively from E, then why should H be not about E or $\neg E$?

Upholding 1, on the other hand, seems to be too strong to be demanded from inductive inference: E.g. ordinary confirmation theory licenses $E \mid\!\sim H$ via high enough $conf(H, E)$ in many cases where $H \nvdash E$.

In general, one can invalidate (PRID), again by employing the overfitting-argument from model selection.

Resolving the Inconsistency II

Invalidity of (PRID)

An overfitting-argument against (PRID):

1. Assume: $E \mid\!\sim H$ and H to be consistent
2. Assume furthermore: $H \nvdash \neg E$
3. Then H either perfectly fits E ($H \vdash E$) or H is indetermined regarding E ($H \nvdash \neg E$, but also $H \nvdash E$).
4. That H is indetermined regarding E is implausible, since $E \mid\!\sim H$ (in model selection E or $\neg E$ is always covered by H).
5. On the other hand, if H perfectly fits E, then H is prone to overfit E, i.e. fit errors in D.
6. Hence neither $H \vdash E$ should be demanded, nor $H \nvdash \neg E$.
7. Hence (PRID) is wrong.

Summary

We have outlined the Newtonian research programme: theoretical part: axioms; methodological part: *regulæ philosophandi*.

We have seen that the methodology (Newton's method) relevantly contains:

- abduction (Analysis)
- induction (Analysis)
- deduction (Synthesis)

We presented a common argument on practical inconsistency of Newton's actual procedure: Basis for the inductive part of analysis (Kepler's laws) is inconsistent with its result (Newton's theory)

We have identified (PRID) (principle on relation induction-deduction) as relevant premise.

We have argued against (PRID) by help of overfitting-considerations.

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