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Principles in Newton's Natural Philosophy

Kirsten Walsh (Philosophy, Nottingham)

Abstract

Newton's great work of 'rational mechanics' is supposedly about principles. They're even in the title: *Philosophiæ naturalis principia mathematica*. However, Newton's use of the term 'principle' appears to be *unsystematic* and *opaque*. Was 'principle', then, just a 'buzz-word' for Newton? Or is there something important underlying his use of the term? I support the latter. While the term 'principle' did not play a central role in Newton's methodology (indeed, I will suggest that *hypotheses* and *theories* are the important concepts for Newton), once we disambiguate his usage, something systematic arises. What it takes to be a principle, by Newton's lights, is to *play a certain kind of role*.

0 Introduction

Natural philosophy should be founded not on metaphysical opinions, but on its own principles (An unpublished preface to the *Principia*).¹

As this volume attests, principles *mattered* in the early modern period. Calling a proposition a 'principle' signalled its importance. It told you that the proposition was, for example, foundational, universal, essential, self-evident or demonstrable. Principles played a central role in the philosophies of Leibniz, Spinoza and Hume, to name just a few of the figures featured in this volume.

Newton's great work of 'rational mechanics' is supposedly about principles. It's even in the title: *Philosophiæ naturalis principia mathematica* (*Mathematical Principles of Natural Philosophy*). And in his preface to the first edition (1686), Newton expressed his hope that

¹ Translation quoted in (Newton, 1999: 54). I. Bernard Cohen has dated this draft to the years following the publication of the second edition of the *Principia* (1713) (Newton, 1999: 49).

“the principles set down here will shed some light on either this mode of philosophizing or some truer one” (Newton, 1999: 383). Statements such as this one, and the choice of title, suggest that principles had an important role to play in Newton’s natural philosophy. In view of this, one might have several expectations. Firstly, given the huge amount of Newton scholarship conducted over the last three hundred years, one might expect some of Newton’s commentators to have carried out conceptual analysis of Newton’s use of the term ‘principle’. Secondly, given his emphasis on principles, one might expect that Newton used the term in a systematic and transparent way.

One might be disappointed.

Newton’s commentators have spent a lot of time analysing key terms, such as ‘force’ (e.g. Janiak, 2007, Westfall, 1971), ‘hypothesis’ (e.g. Cohen, 1962, Cohen, 1969, Walsh, 2012b), ‘cause’ (e.g. Janiak, 2013, Schliesser, 2013), ‘experimental philosophy’ (e.g. Shapiro, 2004), ‘query’ (e.g. Anstey, 2004), ‘explanation’ (e.g. Ducheyne, 2012: 47-49) and ‘*experimentum crucis*’ (e.g. Bechler, 1974, Jalobeanu, 2014)—to name just a few! But there has been surprisingly little analysis of his usage of the term ‘principle’.² I shall redress this oversight by exploring the notion of a principle in Newton’s natural philosophy.

Moreover, Newton’s use of the term ‘principle’ appears to be *unsystematic* and *opaque*. As we shall see, on first appearances, Newton’s use of the term is rough and messy. Was ‘principle’, then, just a ‘buzz-word’ for Newton? Or is there something important underlying his use of the term? I support the latter. While the term ‘principle’ did not play a central role in Newton’s methodology (indeed, I will suggest that *hypotheses* and *theories* are the important concepts for Newton), once we disambiguate his usage, something systematic arises. What it takes to be a principle, by Newton’s lights, is to *play a certain kind of role*.

I’ll proceed as follows. In section 1, I examine the principles in Newton’s published work, both his *Principia* and his *Opticks*. I show, firstly, that Newton used the term in two ways, so I distinguish between *propositional-principles* and *ontic-principles*. Then, focusing more closely on the propositional-principles, I show, secondly, that Newton applied the label ‘principle’ to propositions that (a) are deduced from phenomena and (b) function as premises in his inferences. In section 2, I give an account of Newton’s propositional-

² The only obvious exception to this is J. E. McGuire’s brief discussion of principles in (McGuire, 1970). However, the scope of McGuire’s conceptual analysis doesn’t include Newton’s published work.

principles in their broader methodological context. Drawing on Newton's epistemic distinction between theories and hypotheses, I argue that Newton's propositional-principles are a kind of theory. I then show that what differentiates Newton's principles from other kinds of theories is the function they serve—Newton's principles support his mathematico-experimental method in a crucial way. In section 3, I test my account by turning to a draft manuscript, in which Newton enumerated four 'Principles of Philosophy'. Here, my account of principles is illuminating: of those so-called 'principles', only the ones that (a) are deduced from phenomena and (b) function as premises became principles in Newton's published work. From this discussion, a particular feature of Newton's use of the term 'principle' emerges: labelling or referring to a proposition as a 'principle' tells us about the *function*, rather than the *content*, of the proposition. I argue that this highlights a more general lesson, namely, that when we study Newton's methodology, we should emphasise functions and distinctions over content. And so, I digress to study a case that illustrates this broader point. I conclude that Newton's application of the label 'principle' is exactly what we should expect, given his methodology.

1 Two Kinds of Principles

Newton's use of the term 'principle' appears to be *opaque* and *unsystematic*. Firstly, it is not at all clear what kind of thing the term 'principle' is supposed to pick out. Neither the *Principia* nor the *Opticks* contains any propositions explicitly labelled 'principle'. Instead, the term is found in the discussions following the introduction of new propositions. That is, while no propositions are *labelled* 'principle', many propositions are *referred* to as 'principles' in the *scholia*. So a careful reading is required to figure out what the principles are. Secondly, once we identify the principles in Newton's work, it still seems that his use of the term is neither predictable, nor consistent. One might assume, for example, that the '*principia mathematica*' referred to in the title of Newton's work are the propositions labelled 'laws'. However, when the term principle appears in the *Principia*, it refers variously to the laws, lemmas, other mathematical propositions and philosophical propositions.³ Moreover, in the *Opticks*, the term refers to the axioms of optics, universal

³ 'Philosophical propositions', or *Natural* philosophical propositions, are propositions concerning natural bodies and motions, as opposed to abstract mathematical ones.

gravitation, and the forces, powers and dispositions relating to the behaviour of light. So, at first glance, Newton’s use of the term ‘principle’ appears to be unsystematic.

Newton’s usage, however, becomes clearer once we disambiguate between two kinds of principles: *propositional-principles* and *ontic-principles*.⁴ Table 1 below summarises the key features of these two kinds of principles.

Propositional-Principle	Ontic-Principle
<i>A truth or proposition on which others depend.</i>	<i>A power, force or disposition.</i>
<ol style="list-style-type: none"> 1. A claim about a thing 2. Functions as a premise 3. Known from the phenomena 4. Truth-apt 	<ol style="list-style-type: none"> 1. The thing itself 2. Functions as a cause 3. Known from the phenomena 4. Not truth-apt
E.g. laws of motion, mathematical propositions, theory of universal gravitation, the <i>Opticks</i> axioms	E.g. the cause by which light is reflected and refracted, forces of attraction, passive and active forces.

Table 1 Two kinds of principles.

In this section, I shall consider some examples of both kinds of principles. But before we begin, there are several things to notice about this distinction. Firstly, these are related notions. Very broadly-speaking, principles are *foundational* in both senses. Propositional-principles are foundational in that they are the *premises* from which other propositions are inferred. Ontic-principles are foundational in that they are the *causes* of phenomena. Secondly, these two notions are not well differentiated in Newton’s work. In particular, we shall see that Newton’s laws of motion have an ambiguous status in this classification.

1.1 Principles in the Principia

Since we are interested in principles, it seems fitting to begin with the *Principia*. Here, we will find propositional-principles, but not ontic-principles.⁵

⁴ Here I follow Peter Anstey’s distinction between propositional and ontological principles (see the introduction to this volume).

⁵ In section 1.2 we shall see that, in the *Opticks*, some of these are treated as ontic-principles.

In the *Principia*, Newton started with a set of axioms—his *laws of motion*. These provided the fundamental mathematical conditions from which his system would be built. Armed with his mathematical machinery—a geometrical form of infinitesimal calculus introduced in a series of lemmas in book 1 section 1—Newton proceeded, in books 1 and 2, to explore the mathematical consequences of his laws. These, increasingly complex, mathematical consequences were stated as a series of ‘propositions’, and further labelled as either ‘theorems’ or ‘problems’. These propositions addressed topics such as the laws and effects of centrally directed forces, the three-body problem, the motion of minimally small bodies, the effects of air resistance on pendulums, wave motion and the motion of sound, and the physics of vortices.⁶ In book 3, Newton shifted from considering an abstract mathematical system to a concrete physical system: the system of the world. Armed with a set of ‘rules for the study of natural philosophy’ and a list of ‘phenomena’ (detailing the motions of the planets and the moon), Newton employed the mathematical propositions from books 1 and 2 to infer his theory of universal gravitation, and then to apply it to other phenomena such as the shape of the Earth, the precession of the equinoxes and the motions of comets.

As I noted above, in the *Principia*, Newton did not *label* any proposition a ‘principle’, but he did *refer* to various propositions as ‘principles’. For instance, in the scholium to the laws of motion, where he provided justification for the laws, he referred to them as ‘principles’. He wrote, “The principles I have set forth are accepted by mathematicians and confirmed by experiments of many kinds” (Newton, 1999: 424). However, the term ‘principle’ did not just apply to the axioms or laws of motion. Evidently, it had a broader application. For example, in the scholium at the end of section 1, in which Newton provided a mathematical system in the form of a series of lemmas, Newton referred to

⁶ While these topics suggest that books 1 and 2 deal with physical problems, these are treated as abstract mathematical problems. For, as Newton explained in the scholium at the end of book 1 section 11:

Mathematics requires an investigation of those quantities of forces and their proportions that follow from any conditions that may be supposed. Then, coming down to physics [i.e. natural philosophy], these proportions must be compared with the phenomena, so that it may be found out which conditions of forces apply to each kind of attracting bodies. And then, finally, it will be possible to argue more securely concerning the physical species, physical causes, and physical proportions of these forces (Newton, 1999: 589).

the lemmas as ‘principles’. He explained that he had included the lemmas to provide preliminary proofs of his mathematical tools so that he wouldn’t have to present them in detail later. For,

[...] we shall be on safer ground using principles that have been proved. [...] Moreover,] the force of such proofs always rests on the method of the preceding lemmas (Newton, 1999: 441-442).

Furthermore, at the beginning of book 3, Newton referred to the (mathematical) propositions in books 1 and 2 as ‘principles’:

In the preceding books I have presented principles of philosophy that are not, however, philosophical but strictly mathematical—that is, those on which the study of philosophy can be based. These principles are the laws and conditions of motions and of forces, which especially relate to philosophy [...] It still remains for us to exhibit the system of the world from these same principles (Newton, 1999: 793).⁷

Among other things, these principles include the laws of Keplerian motion.⁸ Some of the philosophical propositions of book 3 were also referred to as ‘principles’. For example, in book 3 proposition 22, Newton wrote, “*All the motions of the moon and all the inequalities of its motions follow from the principles that have been set forth*” (Newton, 1999: 832). In this context, the ‘principles’ include Newton’s theory of universal gravitation.

⁷ In this passage, Newton made a distinction between *philosophical* and *mathematical* principles. Philosophical principles are those that describe natural phenomena, and are more properly called ‘natural philosophical principles’. Mathematical principles are those that concern abstract mathematics or geometry. Newton’s distinction between mathematical and philosophical propositions is important for the status of the *Principia* as a work of natural philosophy. But it’s not important for the status of these propositions as principles. As we shall see, they are called ‘principles’ because they perform the same general methodological function.

⁸ Keplerian motion can be defined by three rules now known as ‘Kepler’s laws’:

1. The orbit of a planet is an ellipse, with the sun at one of the two foci;
2. A line segment joining a planet and the Sun sweeps out equal areas in equal times (this is often called the ‘area rule’); and
3. The square of the orbital period of a planet is proportional to the cube of the semi-major axis of its orbit (this is often called the ‘harmonic rule’ or the ‘3/2 power rule’).

See (Wilson, 2000) for an account of how these propositions came to be regarded as ‘laws’.

So far, we've seen that, in the *Principia*, Newton's use of the term 'principle' was sporadic and obscure. He did not use the term often. But when he did, he used it to refer to a range of propositions—certainly not just the laws of motion. It might appear that Newton was using the term 'principle' haphazardly, as a generic term for any kind of claim or statement. But there are two constraints on Newton's use of the term. The first constraint is that each of the propositions referred to as a 'principle' had high epistemic status (at least according to Newton). We have seen that Newton considered his laws of motion to have been confirmed by experiment and the lemmas proved mathematically. The rest of the mathematical propositions followed deductively from the laws and lemmas, and so were considered certain too. Finally, the philosophical propositions were deduced from mathematical propositions and the phenomena, which, in Newton's mind, made them certain too. As we shall see, Newton considered all these propositions, including the laws, to have been 'deduced from phenomena'.⁹ Moreover, Newton did not use the term 'principle' to refer to hypotheses or queries—i.e. those propositions that were not deduced from phenomena, and so, uncertain.¹⁰ The second constraint is that, each time Newton referred to a proposition as a 'principle', it was functioning as a premise. This tells us that, for Newton, the term 'principle' was context-specific: the proposition was playing a foundational role in the context of a particular argument or inference. This gives us two conditions for calling a proposition a 'principle':

- a) It is deduced from the phenomena; and
- b) It functions as a premise.

Now let's turn to the *Opticks*, in which Newton employed both kinds of principles.

1.2 Principles in the Opticks

The *Opticks* begins in a similar way to the *Principia*—with a list of 'axioms'. However, these axioms are of a different sort to Newton's laws of motion. Where the laws of

⁹ Newton frequently used the phrase "deduced from the phenomena" (e.g. Newton, 1999: 943). However, he didn't always use the terms 'deduction' and 'induction' in their modern technical senses (Shapiro, 2004: 211-215). Therefore, in keeping with Newton's style of usage, I shall tend to use 'deduced' interchangeably with the less technical 'inferred'. For accounts of Newton's use of the terms 'deduction' and 'induction', see for example (Davies, 2003, Ducheyne, 2005, Fox, 1999, Worrall, 2000).

¹⁰ I shall address Newton's distinction between certainty and uncertainty in section 2.

motion are about forces or causes of motion, the axioms of the *Opticks* describe generalised regularities or correlations.¹¹ For example:

Axiom I *The Angles of Reflexion and Refraction, lie in one and the same Plane with the Angle of Incidence.*

Axiom II *The Angle of Reflexion is equal to the Angle of Incidence.*

Axiom III *If the refracted Ray be returned directly back to the Point of Incidence, it shall be refracted into the Line before described by the incident Ray* (Newton, 1952: 5).

These are statements about the geometrical properties of light. They had been established by experiment and so they meet condition (a), they are deduced from phenomena. Following these axioms, Newton wrote:

I have now given in Axioms and their Explications the sum of what hath hitherto been treated of in Opticks. For what hath been generally agreed on I content myself to assume under the notion of Principles, in order to what I have further to write. And this may suffice for an Introduction to Readers of quick Wit and good Understanding not yet versed in Opticks (Newton, 1952: 19-20).

This passage indicates that, as far as Newton was concerned, these axioms were uncontroversial. They were supposed to provide a summary of the current state of optics; the basic mathematics required for geometrical optics. Moreover, the passage states that these axioms would feature as basic assumptions in Newton's treatise. Thus, that they would provide a foundational role in the inferences in the *Opticks*.¹² And so they also meet condition (b), they function as premises.

As with the *Principia*, in the *Opticks*, the term 'principle' emerges repeatedly. Whereas the first usage looks similar to those we saw in the *Principia*, other usages look very different: they are ontic-principles. Firstly, the term refers to the cause by which light is reflected and refracted. For example, in book 3 query 4, Newton wrote:

¹¹ For a discussion of these differences, see (Ducheyne, 2012: 219-222).

¹² In the *Opticks*, Newton didn't make explicit reference to the axioms in his 'proofs'. However, Peter Achinstein has pointed out that we can only make sense of the proofs once we recognise that the axioms are implicitly assumed (Achinstein, 1991: 44, n. 28). Thus, it seems plausible to regard Newton's axioms as hidden premises in his arguments.

Do not the rays of Light which fall upon Bodies, and are reflected or refracted, begin to bend before they arrive at the Bodies; and are they not reflected, refracted and inflected by one and the same Principle, acting variously in various circumstances? (Newton, 1952: 339)

In this passage, the term ‘principle’ applies to some sort of mechanism or power which causes light to bend. There are similar usages of the term in books 1 and 2.

Secondly, the term is used to describe forces of attraction. For example, in book 3 query 31, Newton asked:

Have not the small Particles of Bodies certain Powers, Virtues, or Forces, by which they act at a distance, not only upon the Rays of Light for reflecting, refracting, and inflecting them, but also upon one another for producing a great Part of the Phænomena of Nature? (Newton, 1952: 375-376)

Arguing that we can only learn about such powers, virtues or forces by studying their effects, he went on to discuss gravitational attraction, magnetic attraction, electrical attraction and finally chemical reactions, eventually asking:

[...] is it not for want of an attractive virtue between the Parts of Water and Oil, or Quick-silver and Antimony, of Lead and Iron, that these Substances do not mix; and by a weak Attraction, that Quick-silver and Copper mix difficultly; and from a strong one, that Quick-silver and Tin, Antimony and Iron, Water and Salts, mix readily? And in general, is it not from the same Principle that Heat congregates homogeneal Bodies, and separates heterogeneal ones? (Newton, 1952: 383)

Here, the term ‘principle’ applies to the forces, powers or dispositions that cause bodies to interact in certain ways.

Finally, in book 3 query 31, Newton distinguished between *active* and *passive* principles. For example, in his discussion of the force of inertia, Newton wrote:

The *Vis inertiae* is a passive Principle by which Bodies persist in their Motion or Rest, receive Motion in proportion to the Force impressing it, and resist as much as they are resisted. By this Principle alone there never could have been any Motion in the World. Some other Principle was necessary for putting Bodies into Motion; and now they are in Motion, some other Principle is necessary for conserving the Motion (Newton, 1952: 397).

Here, Newton tells us that a material body, on its own, is passive—i.e. brute and inanimate. If at rest, it cannot begin to move, and if in motion, it can neither stop completely, nor change speed or direction. This disposition to remain at rest or in motion is what Newton called the *vis inertiae*. Newton conceived of this force of inertia

as a ‘passive principle’. For a material body to change its motion, it requires an *impressed force*—i.e. an external force. Newton conceived of such forces as ‘active principles’. He argued that active principles are necessary, if there is to be any kind of motion in the world.¹³

So in the *Opticks*, ‘principle’ referred to two kinds of things: truths or propositions, and forces, dispositions or powers. In section 1.1, I identified two conditions for calling a proposition a ‘principle’ in that former sense, and we have seen that Newton’s axioms meet both conditions. However, the majority of references to principles in the *Opticks* are references to ontic-principles. Ontic-principles are powers, forces or dispositions that function as causes of phenomena. Thus, the term was used to refer to some unknown cause of some particular effect. It is significant that Newton relied heavily on ontic-principles in the queries to the *Opticks*. These queries, particularly query 31, are well-known for their speculative content. They explore the nature of light, whether it can act on bodies, its relationship to heat, its role in vision, and the nature of luciferous æther. These topics concern a lot of unknown causes. And the main function of the queries was to set out a future research program in order to learn about these causes. These causes could only be discovered by investigating their effects—they could only be known from the phenomena. Thus, the term ‘principle’ seems to be a generic term, denoting some unknown cause of some particular effect.

1.3 Summary

We have seen that, in Newton’s published work, the term ‘principle’ had two different kinds of referent: propositions and things in the world. In the *Principia*, Newton referred to propositions (e.g. axioms, lemmas, mathematical propositions and philosophical propositions) as ‘principles’. Similarly, in the *Opticks*, he used the term to refer to the propositions labelled as ‘axioms’. We found, however, that propositions are not *labelled* as ‘principles’, but only *referred to* as ‘principles’ in specific contexts. Thus, in this first sense, principles are propositions that (a) are deduced from phenomena and (b) function as premises. And so ‘principle’ indicates both the *epistemic status* and the *function* of a proposition. In the *Opticks*, we also found a second, non-propositional, usage of the term. Newton used the term to refer to the powers, forces or dispositions of objects. In

¹³ For more detailed accounts of active and passive principles in Newton’s natural philosophy, see (e.g. Dobbs, 1991: 24-57 & 94-96, Westfall, 1980: 299-310).

this second sense, a principle does not refer to a *claim* about a thing in the world, but to *the thing itself*. Thus, we can distinguish between *propositional-principles* and *ontic-principles*. In the *Principia*, we found only propositional-principles; in the *Opticks*, we found both.

The two kinds of principle were not well-differentiated in Newton's work. For example, in the *Opticks* book 3 query 31, Newton was apparently talking about the laws of motion and universal gravitation as ontic-principles:

It seems to me farther, that these Particles have not only a *Vis inertiae*, accompanied with such passive Laws of Motion as naturally result from that Force, but also that they are moved by certain active Principles, such as is that of Gravity, and that which causes Fermentation, and the Cohesion of Bodies. These Principles I consider, not as occult Qualities, supposed to result from the specifick Forms of Things, but as general Laws of Nature, by which the Things themselves are form'd; their Truth appearing to us by Phænomena, though their Causes be not yet discover'd (Newton, 1952: 401).

However, in his letter to Roger Cotes (28 March 1713), Newton was treating the laws of motion as propositional-principles:

These Principles [in this context, the laws of motion] are deduced from Phænomena & p general by Induction: w^{ch} is the highest evidence that a Proposition can have in this Philosophy. (Newton, 1959-1977: V, 396-397).

I do not think there is any contradiction here. In some situations, Newton was thinking about the laws as causes in the world; in other situations, Newton was thinking about the laws as axioms in a mathematical system.

Neither of these notions is a typical usage of the term 'principle' in early modern philosophy. Consider, for example, the entry for 'principle' in John Harris' *Lexicon technicum* (1708). Harris described 'principle' as "a word very commonly and very variously used" (Harris, 1708). He provided six different uses of the word:

- 1) "a maxim, an Axiom, or a good Practical Rule of Action";
- 2) "a Thing Self-evident, and as it were Naturally known, and then 'tis usually called, a *First Principle*";
- 3) "Radiments or Elements; as when we say, the *Principles of Geometry, Astronomy, Algebra*; we mean the Doctrine or Rules of those Sciences";
- 4) "in Chymistry particularly, 'tis taken for first Constituent and Component Particles of all Bodies";

- 5) In ‘modern chymistry’, “there are five kinds, or different Sorts of Bodies, which may by Fire be drawn from many mix’d Natural Bodies, and therefore which may in a large sense be called *Principles*”; and
- 6) In a general sense, “the first cause of any Things *Existence*, or *Production*, or of its becoming *Known* to us”, such as the Aristotelian elements of earth, water, air and fire, the Epicurean principles of magnitude, figure and weight, and Boyle’s mechanical principles of matter, motion and rest.

The first usage is intended in a moral or religious context, and doesn’t capture the usage of Newton’s propositional-principles. Nor does (2), for Newton’s principles were not self-evident, but deduced from phenomena. Newton’s propositional-principles might, to some extent, be characterised by (3). However, Newton’s usage of the term was both broader and more nuanced than this suggests. Usages (4) and (5) are ‘ontological’, as opposed to ‘propositional’. However, where Newton’s ontic-principles refer to forces, powers or dispositions, these chymical principles refer to entities. As Newman’s chapter in this volume attests, the latter is a more typical application of the term. Finally, Newton’s principles cannot be characterised by (6), since, as we shall see, Newton didn’t conceive of his principles as the first causes. Rather, he thought there were further causes to discover.

In the *Opticks* book 3 query 31, Newton made the following statement about principles:

But to derive two or three general Principles of Motion from Phænomena, and afterwards to tell us how the Properties and Actions of all corporeal Things follow from those manifest Principles, would be a very great step in Philosophy, though the Causes of those Principles were not yet discover’d: And therefore I scruple not to propose the Principles of Motion above-mention’d, they being of very general Extent, and leave their Causes to be found out (Newton, 1952: 401-402).

This passage tells us several things about Newton’s notion of propositional-principles. Firstly, principles should be derived from observation and experiment, i.e. “from Phænomena”. Secondly, principles are foundational in one sense, but not in another. On the one hand, the object is to understand “how the Properties and Actions of all corporeal Things follow from those manifest Principles”. So principles are premises from which other propositions are inferred. That is, they are foundational in that, once obtained, they provide the foundation for other propositions. But on the other hand, “the Causes of those Principles were not yet discover’d”. So principles are not

foundational, since they do not necessarily identify or stipulate first causes (or indeed, any kind of cause!). For, as Newton said in the *Opticks* query 28:

And though every true Step made in this Philosophy brings us not immediately to the Knowledge of the first Cause, yet it brings us nearer to it, and on that account is to be highly valued (Newton, 1952: 370).

Nevertheless, Newton's contemporaries appeared to be comfortable about his usage of 'principle'. So, while his usage was unusual, I take it that it was within the realm of accepted usage. Cotes certainly recognised it as appropriate to call Newton's theory of universal gravitation a 'principle'. For example, in his editor's preface to the second edition, he wrote:

I know indeed that some men, even of great reputation, unduly influenced by certain prejudices, have found it difficult to accept this new principle [of gravity] and have repeatedly preferred uncertainties to certainties (Newton, 1999: 386).

2 The Method of Principles

So far, we have distinguished between propositional-principles and ontic-principles in Newton's methodology. In this section, I shall have a closer look at Newton's use of propositional-principles, in order to understand where principles fit in Newton's methodological framework. I begin by introducing Newton's distinction between theories and hypotheses, which, I argue, is the central epistemic distinction in Newton's methodology. I then show that, in Newton's framework, propositional-principles are a kind of theory. I argue that what differentiates principles from other kinds of theories is neither their epistemic status, nor their content, but rather their function.¹⁴

2.1 Theories and Hypotheses

A well-known feature of Newton's methodology is his distinction between certainty and uncertainty.¹⁵ Newton contrasted the certainty of his own natural philosophical claims with the mere hypotheses and speculations which other philosophers found appealing.

¹⁴ Note that, in this context, 'theory' and 'hypothesis' refer to singular propositional statements as opposed to systems of propositions.

¹⁵ This distinction has been discussed by (e.g. Guicciardini, 2011, Shapiro, 1993, Walsh, 2012a).

Consider, for example, the following methodological statement from Newton's earliest publication, 'A new theory of light and colours', from 1672:

A naturalist would scarce expect to see ye science of [colours] become mathematicall, & yet I dare affirm that there is as much certainty in it as in any other part of Opticks. For what I shall tell concerning them is not an hypothesis but most rigid consequence, not conjectured by barely inferring 'tis thus because not otherwise or because it satisfies all Phænomena (the Philosophers universall Topick,) but evinced by ye mediation of experiments concluding directly & without any suspicion of doubt (Newton, 1959: 96-97).

At the time, this statement was quite scandalous. At a time when the Royal Society valued epistemic responsibility, never claiming certainty when the evidence only supported high probability,¹⁶ Newton was making strong claims to certainty—and apparently without any special warrant!

In fact, Newton thought he was warranted in making such claims, because he had a reliable methodology. Newton's approach was based on the idea that mathematics is a bearer of certainty—if one begins with certain axioms, one can reason deductively to certain theorems without epistemic loss. He thought it was possible to apply this method of reasoning to natural philosophy: one can reason deductively from laws and principles to propositions in natural philosophy. So, if one can establish *certain* natural philosophical laws or principles, it is possible to reason mathematically to *certain* propositions. By reasoning in this way, Newton thought he could achieve a mathematical science. The challenge, then, was to identify laws or first principles that met this requirement of certainty—via *deduction from phenomena*.

Newton's distinction between certainty and uncertainty is best characterised as a distinction between 'theories' and 'hypotheses' (outlined in table 2 below).¹⁷ In Newton's

¹⁶ See, for example, Robert Hooke's 'Preface to the Royal Society' in his *Micrographia* (Hooke, 1966/1665).

¹⁷ Here, I am not simply juxtaposing two terms of reference, but rather, making an epistemic distinction. I use 'theory' and 'hypothesis' as generic terms that are intended to capture a distinction between two kinds of propositions. (By 'proposition' here, I am referring to the meaning of a declarative sentence that is the primary bearer of some truth-value.) Newton rarely used the term 'theory' in his publications. My definition of 'theory' fits his usage of the terms 'law', 'lemma' and 'proposition' (Newton frequently divided his 'propositions' into 'theorems' and 'problems'). Moreover, my definition of

methodology, theories and hypotheses deal with different subject matter, have different epistemic statuses and perform different roles in theorising. Theories systematise the observable, measurable properties of things; hypotheses describe the (unobservable) nature of things. Theories are inferred from observation and experiment; hypotheses are speculative. For example, Newton saw universal gravitation—i.e. the proposition that any two bodies in the universe attract each other with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between them—as a theory, since it was inferred from celestial and terrestrial observations, had empirically testable consequences and was used to systematise those observations. However, an explanation of the nature and cause of gravity would be a hypothesis, since it concerns the unobservable nature of things, and is speculative, rather than inferred from experiment—and thus, any account Newton could give would be, at best, only probable.¹⁸

Theory	Hypothesis
A proposition is a 'theory' iff it meets the following conditions:	A proposition is a 'hypothesis' iff it meets one or more of the following conditions:
T1. It is certainly true, because it is reliably inferred from experiment;	H1. It is, at best, only highly probable; or
T2. It is experimental—something that has empirically <i>testable</i> consequences; and	H2. It is a conjecture or speculation—something not based on empirical evidence; or
T3. It is concerned with the <i>observable, measurable properties</i> of the thing, rather than its nature.	H3. It is concerned with the nature of the thing, rather than its observable, measurable properties.

Table 2 Definitions of 'theory' and 'hypothesis'

'hypothesis' fits Newton's usage of both 'hypothesis' and 'query' (assuming we read the latter as assertions, rather than questions). In Newton's usage, where hypotheses and queries come apart is in the role they play in his natural philosophy (see e.g. Anstey, 2004). For a discussion of the distinction between theories and hypotheses in early modern philosophy more generally, see (Ducheyne, 2013).

¹⁸ It is worth noting that hypotheses are closely related to ontic-principles. 'Principle' refers to an unknown cause of a particular effect. It is typically a place-holder for a force or power to which we don't have epistemic access. A proposition describing the nature or cause of an ontic-principle would be a hypothesis.

The distinction between theories and hypotheses is central to Newton’s methodology. For Newton, theories were on epistemically surer footing than hypotheses because they were grounded on phenomena, whereas the latter were grounded in speculations. And so hypotheses could never trump theories. When faced with a disagreement between a hypothesis and a theory (e.g. suppose our theory seems to imply action-at-a-distance, but the most plausible hypothesis about the nature of motion tells us that action-at-a-distance is impossible), we should modify the hypothesis to fit our theory, and not *vice versa*. The distinction was nicely captured in a draft letter from Newton to Cotes (March 1713):

And therefore as I regard not hypotheses in explaining the phenomena of nature, so I regard them not in opposition to arguments founded upon phenomena by induction or to principles settled upon such arguments. In arguing for any principle or proposition from phenomena by induction, hypotheses are not to be considered. The argument holds good till some phenomenon can be produced against it (Newton, 2004: 120).

While Newton railed against hypotheses—determined to preserve the certainty of his propositions and to avoid epistemic loss by keeping speculative conjectures apart—hypotheses played an important role in Newton’s negotiations between certainty and speculation.¹⁹

In the following section, we’ll see that Newton’s propositional-principles were a kind of theory, but performed a specific role.

2.2 Characterising Principles as ‘Theories’

Newton’s (propositional-) principles were theories. We have already seen that Newton conceived of principles as propositions that had been deduced from phenomena and therefore certain. Thus, they fit the above definition of a ‘theory’. Moreover, in statements such as this one from his letter to Cotes (28 March 1713), Newton explicitly contrasted his principles with hypotheses:²⁰

¹⁹ For an extended discussion of the respective roles of hypotheses and queries in Newton’s natural philosophy, see (Walsh, 2014).

²⁰ This passage highlights a difference between Newton’s and John Locke’s notions of ‘principle’. Where Locke viewed principles as hypotheses (mere probabilities or conjectures), Newton saw principles as theories (i.e. deduced from phenomena and certainly true) (McGuire, 1970: 181). For, unlike Locke,

These Principles [in this case, the laws of motion] are deduced from Phænomena & made general by Induction: w^{ch} is the highest evidence that a Proposition can have in this Philosophy. And the word Hypothesis is here used by me to signify only such a Proposition as is not a Phænomenon nor deduced from any Phænomena but assumed or supposed wthout any experimental proof (Newton, 1959-1977: V, 396-397).

In section 1, we saw that Newton used the term ‘principle’ to refer to several different kinds of proposition: laws, axioms, lemmas, mathematical propositions and philosophical propositions. Where the term ‘theory’ unifies all of these propositions on the basis of their epistemic status, ‘principle’ picks out a certain kind of theory, namely, a theory that functions as a premise. Let us examine the function of a principle more closely by considering the inference structure of the *Principia*.

The inference structure of the *Principia*, loosely goes as follows. Newton started with his laws of motion. He claimed that these laws are supported by experiment. From these laws, with the help of his mathematical tools stated in a series of lemmas (i.e. his geometrical form of infinitesimal calculus), Newton inferred the propositions in books 1 and 2 of the *Principia* (the ‘mathematical propositions’). From the mathematical propositions, and supported by celestial phenomena, Newton inferred his theory of universal gravitation. From his theory of universal gravitation and some planetary observations (more ‘phenomena’), Newton inferred other features of the system, such as his theories of the comets and the shape and motion of the moon.²¹ The tiers of this extended inference are summarised in figure 1 below.

Newton believed that universal statements could be established from phenomena. For an account of how Locke’s notion of a natural philosophical principle developed in light of Newton’s achievements in the *Principia*, see (Anstey, 2011).

²¹ This inference structure has been interpreted as hypothetico-deductivism. For two compelling critiques of this interpretation, see (Harper, 2011: ch. 9) and (Smith, 2014).

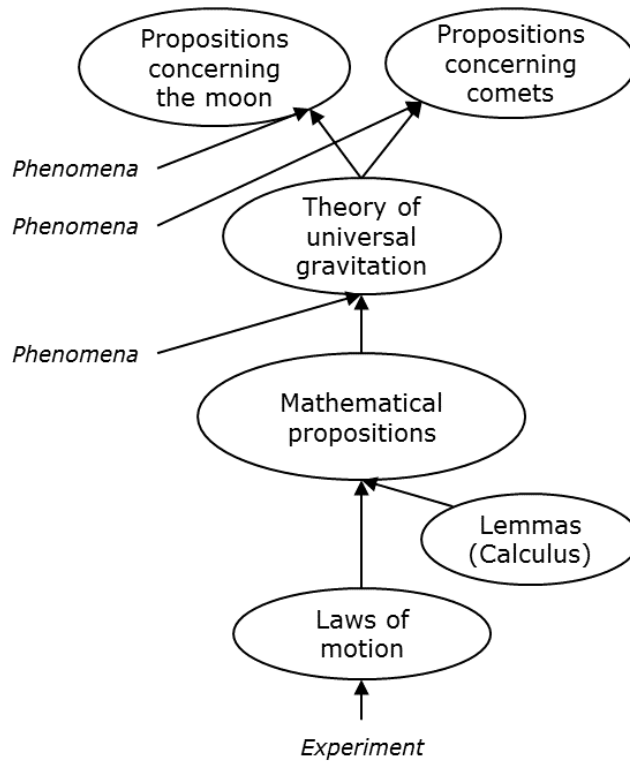


Figure 1 Structure of inference in the *Principia*.

We have seen that Newton applied the term ‘principle’ to propositions at every level of this diagram except the top one. When Newton used the laws of motion to infer his mathematical propositions, he referred to his laws as ‘principles’. Newton referred to his lemmas as ‘principles’ in a similar context. When he used his mathematical propositions to infer his theory of universal gravitation, he referred to them as ‘principles’. And finally, when he used his theory of universal gravitation to develop his propositions concerning comets and the moon, he referred to his theory of universal gravitation as a ‘principle’. In fact, the only propositions listed in figure 1 above that *weren’t* referred to as ‘principles’ in the *Principia* were the propositions concerning the moon and the propositions concerning the comets. In the context of the *Principia*, this is not surprising, since these were the final propositions in the *Principia*—they were not premises for any further arguments.

It should not be surprising, therefore, that these laws and propositions were not labelled as ‘principles’, but only referred to as ‘principles’ in specific contexts. The label was bestowed only circumstantially—to indicate a specific temporary function. It was, nevertheless, an important function. As we saw above, Newton’s mathematico-experimental approach had two crucial components: (1) establishing certain principles by

deducing them from phenomena; and (2) reasoning deductively from those principles to other propositions (maintaining certainty). The *Principia* gave every appearance of following Newton's prescriptions for a mathematico-experimental science. Starting with laws and a strong mathematical framework of lemmas, Newton inferred mathematical propositions and, eventually, philosophical propositions. Moreover, in the scholium to the laws, Newton asserted that they were certainly true, because they had been confirmed by experiment. Thus, he felt warranted in using them to deduce his theory of universal gravitation. And so Newton conceived of principles as a *kind* of theory. Namely, a theory that functioned as a premise in an argument or inference.

2.3 Summary

In section 1, we gleaned two conditions for calling a proposition a 'principle': (a) it has been deduced from phenomena; and (b) it functions as a premise. In this section, we considered where Newton's principles fit in his general methodology. I introduced Newton's distinction between theories and hypotheses—I regard this as a central distinction in Newton's natural philosophy. I argued that, by condition (a), Newton's principles were theories. They were deduced from phenomena and therefore certainly true; as opposed to hypotheses, which were speculative and uncertain. I then argued that condition (b) distinguishes principles from other kinds of theories. Principles are important because they are theories from which other theories are deduced.

I now turn to a test case: a draft manuscript, intended as a preface for the *Opticks*.

3 Some puzzling Principles

In a draft manuscript, originally intended as the preface to the *Opticks*, Newton wrote an account of principles.²² The manuscript, which McGuire has called the 'Principles of Philosophy' (McGuire, 1970), provides the most extensive discussion of principles that can be found in Newton's work. In this manuscript, Newton gave an account of his method of principles and then enumerated the four principles which he regarded as the foundation for his natural philosophy. The manuscript presents a puzzle for my account of Newton's principles, since this is the only place we find principles explicitly labelled as such. Moreover, of the four principles identified in this manuscript, only one of them is referred to as a principle in Newton's published work. Here, we shall find my account of

²² MS. Add. 3970. ff. 479^r-479^v.

principles to be illuminating: of those so-called ‘principles’, only the ones that meet my two conditions for ‘principle’ appear as principles in Newton’s published work.

The manuscript opens with a discussion of methodology, which supports the framework I have outlined. For example, the discussion ends with the following passage:²³

Tis much better to do a little with certainty ~~then to~~ & leave the rest for others that come after, than to explain all things by conjecture ~~& leave~~ without making sure of any thing. And there is no [↑]other[↑] way of doing anything with certainty then by ~~drawing conclusions~~ drawing conclusions from experiments & phenomena untill you come at ~~such~~ general Principles ~~as are~~ & then from those Principles giving an account of Nature. ~~This is ye only~~ Whatever is certain in Philosophy is owing to this method & nothing can be done without it. [↑]I will instance in some particulars.[↑]

The themes in this passage are, by now, familiar to us. Newton’s goal was to produce determinate natural philosophical claims. That is, he wanted to achieve certainty. Thus, in the trade-off between explanatory scope and epistemic strength, Newton chose the latter. As far as Newton was concerned, the only way to achieve certainty in natural philosophy was to start by making observations and experiments, and then to infer general principles from the phenomena. Such general principles would form the basis for an account of nature.

Following these methodological preliminaries, Newton proceeded to enumerate four general principles of philosophy, providing evidence or support for them. I shall discuss them in detail shortly. But for now, I’ll simply summarise them:

- 1) There exists an Intelligent Creator;
- 2) Matter is impenetrable;
- 3) All bodies in the Universe gravitate towards all other bodies in the Universe, in accordance with Newton’s theory of universal gravitation; and
- 4) Sensible bodies are composed of tiny particles of matter with gaps between them.

This manuscript is puzzling. The ‘principles of philosophy’ appear to present a counter-example to my account of Newton’s method of principles, since they do not function as premises. Moreover, it is surprising that these ‘principles’ are labelled as such. As I

²³ Unless otherwise stated, all quotes in this section are from MS. Add. 3970. ff. 479^r-479^v.

pointed out in section 1, this never happened in Newton’s published work. Finally, only one of these (so-called) ‘principles’ was referred to as such in Newton’s published work.

In this section, I argue that the manuscript illuminates a particular feature of Newton’s method of principles, namely, that labelling or referring to a proposition as a ‘principle’ tells us about the *function*, rather than the *content*, of the proposition. In this way, Newton’s method of principles is an example of a more general feature of Newton’s methodology. Thus, in section 3.2 I’ll digress to study a case that illustrates this broader point, namely, that when we study Newton’s methodology, we should emphasise functions and distinctions over content.

3.1 Tracing the principles

This manuscript may appear to present a counter-example to my account of Newton’s method of principles. However, in this section, I shall argue that the manuscript in fact supports my account. My argument rests on the recognition that Newton’s ‘principles of philosophy’ is a draft that was never published. Only one of the propositions was ever referred to as a ‘principle’ in Newton’s published work. Significantly, it was *also* the only proposition that fit both conditions for calling a proposition a ‘principle’. While we can trace versions of the other principles in the *Principia* and the *Opticks*, they are never referred to as ‘principles’. I therefore argue that, while Newton may have *hoped* to present these four propositions as principles, he changed his mind.

Let’s start by considering the proposition that *was* referred to as a ‘principle’ in print: principle (3), Newton’s theory of universal gravitation. That is, that “all ~~the great~~ bodies in y^e Universe have a tendency towards one another proportional to y^e quantity of matter contained in them & that this tendency in receding from the body decreases & is reciprocally proportional to y^e square of y^e distance from y^e body”.²⁴ In support, Newton summarised the evidence he provided for universal gravitation in the *Principia* book 3. For example, the pendulum experiments that he used in proposition 4 to demonstrate that the force that keeps the moon in orbit is the same force that causes heavy bodies fall to the ground—namely, gravity. And also the evidence for proposition 5: that the moons of Jupiter and Saturn gravitate towards Jupiter and Saturn respectively and the

²⁴ McGuire notes that this is probably the earliest non-mathematical statement of universal gravitation in Newton’s own words (McGuire, 1970: 184, n. 21).

primary planets gravitate towards the Sun, and this force of gravity is responsible for keeping the moons and planets in orbit. And finally, he noted that many comets seem to gravitate towards the Sun as well. In the *Principia*, principle (3) met both conditions for ‘principle’. Firstly, it was ‘deduced’ from celestial and terrestrial phenomena such as the motions of the planets. Secondly, it functioned as a premise from which the motions of celestial bodies such as comets were deduced.

Now consider principle (1), that there exists an intelligent creator: “a God or Spirit infinite eternal omniscient omnipotent”. To support this principle, Newton put forward an argument from design, explaining that “the best argument for such a being is the frame of nature & chiefly the contrivance of y^e bodies of living creatures”. To this end, he pointed firstly to isomorphic traits among land animals, such as the observation that they all have two eyes, a nose and a mouth, and secondly to the ingenuity of the functions of such traits. Asking, for example, “What more difficult then to fly? & y^t had flying creatures their wings by chance? or has any creature wings without being able to fly? & yet was it by chance y^t all creatures can fly wch have wings?” Newton evidently found these arguments from the phenomena extremely compelling:

These & such like considerations are the most convincing arguments for such a being & have convinced mankind in all ages that y^e world & all the species of things therein & were originally framed by his power & wisdom. And to lay aside this argument is ~~very~~ unphilosophical.

The ideas expressed in this passage were clearly very important to Newton, since traces of them can be found in both the *Opticks* and the *Principia*. For example in the General Scholium to the *Principia*, there is an extended discussion of God:

This most elegant system of the sun, planets, and comets could not have arisen without the design and dominion of an intelligent and powerful being [...] It is agreed that the supreme God necessarily exists, and by the same necessity he is *always* and *everywhere* [...] This concludes the discussion of God, and to treat of God from phenomena is certainly a part of natural philosophy (Newton, 1999: 940-943).

The similarities between this passage and the draft passage above are striking. Here, Newton was arguing from design for an intelligent creator. Since arguments for intelligent design rest on observable phenomena of the natural world, Newton argued that understanding God and His creation are legitimate topics for natural philosophy. A similar passage appears in the *Opticks* book 3 query 31:

Now by the help of these Principles [in this context, the laws of motion], all material Things seem to have been composed of the hard and solid Particles above-mention'd, variously associated in the first Creation by the Counsel of an intelligent Agent. For it became him who created them to set them in order. And if he did so, it's unphilosophical to seek for any other Origin of the World, or to pretend that it might arise out of a Chaos by the mere Laws of Nature; though being once form'd, it may continue by those Laws for many Ages (Newton, 1952: 402).

Principle (1) wasn't referred to as a principle in the *Principia* or the *Opticks*. And not because it wasn't deduced from the phenomena—indeed, Newton thought that it had been deduced from the phenomena and was certainly true. Rather, principle (1) didn't appear as a principle because it never functioned as a premise, and thus, didn't perform the role of a principle. That is, it meets condition (a) but not condition (b).

Now consider principle (2), that matter is impenetrable. Newton explained, “This is usually looked upon as a maxim known to us by y^e light of nature, altho we know nothing of bodies but by sense”. That is, while others have taken this principle to be self-evident, Newton thought that compelling support for this principle would come only from sensory experience and the absence of counter-instances. He explained:

And such observations occurring every day to every man this property of bodies is acknowledged by all ~~man~~ men without any dispute & looked upon as an Axiom.²⁵

Newton was clearly committed to principle (2). He thought that it was well-established and even deduced from phenomena. It never appeared as a principle in the *Principia* or the *Opticks*, and yet, traces of this principle are found in both works. For example, in the *Opticks* book 3 query 31, Newton wrote:

[...] this seems to be as evident as the universal Impenetrability of Matter. For all Bodies, so far as Experience reaches, are either hard, or may be harden'd; and we have no other Evidence of universal Impenetrability, besides a large Experience without an experimental Exception (Newton, 1952: 389).

²⁵ Newton often mentioned agreement among philosophers or mathematicians in discussions of empirical support. Elsewhere I have argued that we should understand Newton's notion of certainty as 'compelled assent' (Walsh, Forthcoming): the evidence compelled him undeniably to his conclusion. I take it that agreement among scholars supported this undeniability, the thought being that no rational person, having carried out the experiment, could deny the conclusion.

Again, the similarities between this published passage and the draft passage are striking. The impenetrability of matter is established from experience without exception—that is, from the phenomena. The same idea is expressed in the *Principia* book 3, where Newton used the impenetrability of matter as his main example of the application of rule three.²⁶

He wrote:

That all bodies are impenetrable we gather not by reason but by our senses. We find those bodies that we handle to be impenetrable, and hence we conclude that impenetrability is a property of all bodies universally (Newton, 1999: 795).

Newton argued that the proposition that matter is impenetrable was deduced from the phenomena, so it met condition (a). However, the impenetrability of matter never functioned as a premise, and thus, didn't perform the role of a principle. That is, it met condition (a) but not condition (b).

Finally, consider principle (4), that sensible bodies are composed of tiny particles of matter with gaps between them. That is, “all sensible bodies are aggregated of particles laid together with many interstices or pores between them”. To support this principle, Newton described phenomena such as the absorption of water and other liquids by various substances, the ability of acids to dissolve metals, and the transmission of light through various substances (e.g. air, water, oil and crystals). Evidently, this principle was an important one for Newton's theory of optics:

As by the ~~former~~ ↑third↑ Principle we gave an account ↑heretofore↑ of y^e motions of ~~all~~ the Planets & of y^e flux & reflux of y^e sea, so by this Principle we shall ~~give an acct~~ in y^e following treatise give an acct of y^e permanent colours of natural bodies, nothing further being requisite for y^e production of those colours then that y^e coloured bodies abound with pellucid particles of a certain size & density.²⁷

And yet, it wasn't referred to as a 'principle' in the *Opticks*. In fact, in query 31, Newton argued that the proposition that all sensible bodies are composed of hard particles “seems to be as evident as the universal Impenetrability of Matter” (Newton, 1952: 389).

²⁶ “Rule 3. *Those qualities of bodies that cannot be intended and remitted and that belong to all bodies on which experiments can be made should be taken as qualities of all bodies universally*” (Newton, 1999: 795).

²⁷ That “the following treatise” deals with colour tells us that this draft is intended for the *Opticks* rather than the *Principia*.

But in query 31 he was more interested in how the particles of matter stick together, than in what follows from this idea. He concluded:

There are therefore Agents in Nature able to make the Particles of Bodies stick together by very strong Attractions. And it is the Business of experimental Philosophy to find them out (Newton, 1952: 394).

And so, Newton thought that the proposition that all sensible bodies are composed of tiny particles of matter with gaps in them was true, and presumably deduced from the phenomena. But when it was introduced in query 31, Newton's focus was different. Instead of using this proposition to deduce the properties of coloured bodies, Newton wanted to understand how the particles cohere. So this proposition might have met condition (a) but certainly not condition (b).

To summarise, while all four of Newton's 'principles of philosophy' can be traced in Newton's published work, only one of them was referred to as a 'principle'. Moreover, that principle was the only one that met the two conditions for being a principle. This case highlights something important about how we should view Newton's principles. If we focus on content, they look unsystematic. But when we focus on function, Newton's use of the term starts to look systematic and important. Thus, if we want to understand how Newton used the term 'principle', we should focus on the functions of principles, rather than their content. In fact, this lesson can be generalised. Newton's approach to the term 'principle' was similar to his approach to other methodological terms such as 'hypothesis', 'rule' and 'query'. Namely, the label emphasised the function of the proposition, rather than its content. In the next section, I shall illustrate this general point with a case study.

3.2 Labelling propositions: a case study

I have argued that, when considering Newton's use of principles, we should emphasise functions over the content of propositions. When we focus on the functions of the principles, rather than their content, Newton's method of principles looks much more systematic. I now argue that this is a much more general feature of Newton's methodology. In Newton's work, it was entirely possible for the same proposition or idea to appear in one context with one label, and in another context with a different label. I think this is a fairly important lesson about how to understand Newton's

methodology. So I shall briefly digress to illustrate this general point by examining another draft manuscript: a plan for the fourth book of the *Opticks*.²⁸

Several drafts of the *Opticks* book 4 exist in various stages of development.²⁹ The topic of book 4 was to be “the nature of light & ye power of bodies to refract and reflect it”. One draft begins with a list of three items under the heading ‘Observations’:³⁰

- 1 Of ye 3 faciae of colours made by inflected light.
- 2 Of bent of several rays wch passe at several differences from ye edge of ye knife.
- 3 Conclusions concerning ye vernicular motions of ye inflected rays.

These are clearly topics to be covered by the observations, rather than the observations themselves.³¹

The draft that I shall focus on here contains a list of propositions.³² But since, as Alan Shapiro has pointed out, this is a draft of an outline or plan of the book, rather than a draft of the book itself, it contains little in the way of argument and virtually no discussion of experimental evidence (Shapiro, 1993: 141-143). Thus, the propositions are things that Newton *hoped* to prove. For example:

- Prop. 1. The refracting power of bodies in vacuo is proportional to their specific gravities.
- Prop. 2. The refracting power of two contiguous bodies is the difference of their refracting powers in vacuo.

Newton listed about twenty propositions before he made a structural change: he went back to proposition 17 and relabelled it ‘hypothesis 1’. He also added a heading: ‘The Conclusion’. Then he began to re-number the propositions that followed. By the time

²⁸ In the late 1680s, Newton conceived of the *Opticks* as a four-volume work. However, by the early 1700s, the *Opticks* had been re-written in three volumes. Much of the material from book 4 was incorporated into book 3 of the *Opticks*. For a discussion of the delay in publishing the *Opticks*, see (Shapiro, 2001).

²⁹ MS. Add. 3970, ff. 335^r-336^v, 337^r-340^v, 342^r-343^r.

³⁰ MS. Add. 3970, ff. 342^r-343^r

³¹ And these are the topics covered by the observations that were eventually published in book 3 of the *Opticks*.

³² MS. Add. 3970, ff. 337^r-338^v.

Newton had finished with it, the draft contained eighteen propositions and a conclusion consisting of five hypotheses.

Let's focus on 'Hypothesis 2', which I shall quote *in extenso*.³³

~~Prop 18~~ ↑Hypoth 2↑. As all the great motions in the world depend upon a certain kind of force (~~vulgarly called gravity~~ wch in this earth we call gravity) whereby great bodies attract one another at great distances: so all the ~~minute~~ ↑little↑ motions in ye world depend upon certain kinds of forces whereby minute bodies attract or dispell one another at little distances.

How ~~all the great motions~~ {illeg.} are regulated by the gravity of ↑which↑ great bodies ↑have↑ towards one another I shewed at large in my ↑Philosophiae↑ Principia mathematica {illeg.} ↑the great bodies of ye earth Sun ↑moon↑ & Planets gravitate towards one another what↑ are ye laws of & quantities of their gravitating forces at all distance from them & how {illeg.} all ye motions of those bodies are regulated by those their gravities I shewed in my Philosophiae naturalis Principia mathematica by such a convincing ↑mathematical↑ way of arguing as has given satisfaction ~~procured the assent of~~ {illeg.} as many {illeg.} all the ablest ↑mathematicians {illeg.} have {illeg.} ↑who have had leasure to↑ had leasure & skill to examine the book-Mathematical Principles of Philosophy ↑to the satisfaction of my readers↑: And if Nature be most simple & ↑fully↑ consonant to her self she observes the same method in regulating the motions of smaller bodies wch she doth in regulating those of the greater. ↑But what↑ This principle of nature being very remote from the conceptions of {illeg.} Philosophers I forbore to describe it in my Principles ↑that said Book↑ least I should be accounted an extravagant freak & so prejudice my Readers against all those things wch were ye main designe of ~~only that~~ the Book: but {illeg.} those things being received by ~~Mathematicians~~ & yet I hinted at it both in the Preface of ↑& in↑ ye book it self where I speak of the inflection of light & of ye ~~a refraction of &~~ elastic power of ye Air: but the design of ye book being secured by the approbation of Mathematicians, I had not ~~doubted~~ ↑scrupled↑ to propose this Principle in {illeg.} plane words. The truth of this Hypothesis I assert not because I cannot prove it, but I think it very probable because a great part of the phaenomena of nature do easily flow from it wch seem otherways inexplicable [...] (MS. Add. 3970, fols. 338v).

I. Bernard Cohen has described this as “a ‘whale’ of an hypothesis” (Cohen, 1969: 320)—and he’s right! When Newton started writing out this statement, he intended for it to be ‘Proposition 18’—a theory. But at some point, he scratched out ‘Prop 18’, and re-branded it as ‘Hypoth 2’. As we’ve seen, for Newton there was an important epistemic shift here. Theories were things that he was able to assert as true. Hypotheses were things that he was unable to assert, because he did not have the evidence. Newton

³³ The draft has been heavily edited, and so many of the words are illegible.

probably hoped to assert Proposition 18. But as he started to explicate it, he must have realised that he couldn't prove it. Thus, he re-labelled it as a hypothesis—something speculative and, thus, uncertain. Newton also made it clear that he wanted to use this as a principle, but he wasn't certain of it, so he couldn't.

When Newton abandoned the idea of a fourth book, and restructured his *Opticks*, this 'Hypothesis 2' appears to have been re-worked to become part of 'Query 31' in the *Opticks*.³⁴

Have not the small Particles of Bodies certain Powers, Virtues, or Forces, by which they act at a distance, not only upon the Rays of Light for reflecting, refracting, and inflecting them, but also upon one another for producing a great Part of the Phaenomena of Nature? For it's well known, that Bodies act one upon another by the Attractions of Gravity, Magnetism, and Electricity; and these Instances shew the Tenor and Course of Nature, and make it not improbable but that there may be more attractive Powers than these. For Nature is very consonant and conformable to her self [...] (Newton, 1952: 375-376).

Moreover, similar themes appear in the *Principia* book 1. This is a much more technical discussion in which Newton aimed to solve “*the motion of minimally small bodies that are acted on by centripetal forces tending toward each of the individual parts of some great body*” (Newton, 1999: 622). In the scholium to propositions 94, 95 and 96, Newton noted that:

These attractions are very similar to the reflections and refractions of light made according to a given ratio of the secants, as Snel discovered, and consequently according to a given ratio of the sines, as Descartes set forth. [...] Moreover, the rays of light that are in the air [...] in their passing near the edges of bodies, whether opaque or transparent [...] are inflected around the bodies, as if attracted toward them; and those of the rays that in passing approach closer to the bodies are inflected the more, as if more attracted [...]. And those that pass at greater distances are less inflected [...]. Therefore because of the analogy that exists between the propagation of rays of light

³⁴ While there is an obvious semantic shift between hypothesis and query—the query is stated as a question—this difference is often ignored. Queries are often interpreted as assertions. Some scholars have argued that this is the *only* difference between hypotheses and queries: in the *Opticks*, queries were simply Newton's way of getting around his self-imposed ban on hypotheses. There is something to this suggestion: there is a sense in which the queries employed in the *Opticks* may be considered *de facto* hypotheses. However, there is more to the shift than this. Newton was using the semantic structure of the query to explore a possible future research program. So, while Newton couldn't prove it himself, he felt that it was the kind of thing that could be dealt with in his natural philosophy.

and the motion of bodies, I have decided to subjoin the following propositions for optical uses [...] (Newton, 1999: 625-626).

And in Newton's discussion of 'Rule 3' in the *Principia*, he wrote: "[...] nor should we depart from the analogy of nature, since nature is always simple and ever consonant with itself" (Newton, 1999: 795). And finally, in Newton's discussion of proposition 6 in the *Opticks* book 1 part I, he wrote: "That this should be so is very reasonable, Nature being ever conformable to her self; but an experimental Proof is desired" (Newton, 1952: 76).

The lesson is simple. Here, we have seen that similar ideas emerged in different contexts throughout Newton's work. The same content was variously referred to as a 'hypothesis', a 'rule', a 'proposition', a 'principle', and even a 'query', depending on what role it was playing. This tells us that, if we want to understand Newton's usage of a methodological term such as 'principle' or 'hypothesis', we should look at what work the idea is doing, rather than its content. And we cannot expect the same idea to always bear the same label.

3.3 Summary

At the start of this section, I introduced a manuscript concerning Newton's 'principles of philosophy'. We have seen that Newton applied the label 'principle' to things that are deduced from phenomena and function as premises. Newton's 'principles of philosophy' did not necessarily fit these conditions. Moreover, only one of these principles was explicitly labelled as a principle in Newton's published work. Interestingly, however, traces of these principles are found in Newton's published work, though not labelled in the same way. These propositions performed different functions in different contexts. So Newton applied the label 'principle' in particular contexts; rather than to particular propositions in all contexts. This is an example of a more general point about Newton's methodology: when we want to understand how Newton used his methodological terms, we should focus on function, rather than content.

Finally, a comment about Newton's 'Principles of Philosophy'. We should interpret this manuscript very much as a work in progress. Newton was attempting something very ambitious, but it obviously didn't work out. It is striking that these principles don't form a coherent 'system of philosophy'. That is, there is no framework, mathematical or philosophical, that ties the principles together. This suggests that Newton had a different goal in mind, when writing this. He was trying to give an account of his natural

philosophy in broad brush strokes—as befits a preface.³⁵ In his commentary on this manuscript, McGuire sheds some light on this intended preface. He dates the draft to late 1703, not long before the *Opticks* was published (McGuire, 1970: 179). At that time, Newton was focussed on the various conceptual problems arising from his theories of universal gravitation and the composition of light, such as extending the application of the laws of motion to the smallest units of matter. “In general he wished to make clearer the significance of his natural philosophy” (McGuire, 1970: 178). One interesting thing about this manuscript is that we get the sense that Newton conceives of his two great works as two lines of inquiry in a unified natural philosophical project. They are unified by their methodology and by these four principles.

4 Conclusion

In a draft methodological fragment, related to the ‘Principles of Philosophy’, Newton wrote:

Thus in the Mathematical Principles of Philosophy I first shewed ↑from Phænomena↑ that ~~the~~ all bodies endeavoured by a certain force proportional to their matter to approach one another, that this force in receding from y^e body grows less & less in reciprocal proportion to y^e square of the distance from it & that it ~~was~~ ↑is↑ equal to gravity & therefore ~~was~~ ↑is↑ one & the same force with gravity. Then using this force as a Principle of ↑Philosophy↑ ~~gravity, I shewed how~~ I derived from it all the ~~Phænomena of nature~~ motions of the heavenly bodies & the flux & reflux of y^e sea, shewing by mathematical demonstrations that this force alone was sufficient to produce all those Phænomena, & deriving from it (a priori) some ↑new↑ motions w^{ch} Astronomers had not then observed but since appeare to be true, as that Saturn & Jupiter draw one another, that y^e variation of y^e Moon is bigger in winter then in summer, that there is an equation of y^e Moons meane motion amounting to almost 5 minutes w^{ch} depends upon the position of her ~~Apheion~~ Apoge {sic.} to y^e Sun (MS. Add. 3970. f. 480^v).

I have argued that, when considering Newton’s principles, we should focus on function rather than content. And so it is significant that, in this passage, Newton focused on how his theory of universal gravitation was used. Here Newton claimed that his theory of universal gravitation (a) had been deduced from phenomena (i.e. “I first shewed from

³⁵ McGuire has suggested that we should understand these principles in the Boylean sense: they are general claims intended to help to “explicate the already known phenomena of nature” (Boyle, 1772: 301-302, quoted in McGuire, 1970: 180-181). But, where Boyle understands principles *solely* as heuristic aids to the progress of knowledge, Newton construes them as constitutive statements about the natural world.

Phænomena”) and (b) had functioned as a premise (i.e. “I derived from it...”). It is significant for my interpretation of Newton’s principles, that Newton described the latter step as “using this force as a Principle”. I have argued that ‘principle’ was a context-specific term. Any kind of theory could be a principle, provided it served the right kind of function. Therefore, it seems appropriate for Newton to talk of using some concept as a principle.

An important lesson emerged from my discussion of Newton’s method of principles: labelling or referring to a proposition as a ‘principle’ tells us about the *function*, rather than the *content*, of the proposition. I have argued that this is an example of a more general feature of Newton’s methodology, namely, that when we study Newton’s methodology, we should emphasise functions and distinctions over content. Newton’s use of the term ‘principle’ fits, what I call, his ‘rhetorical style’. Newton took the already familiar term and stretched it to fit his methodology. It is well known that Newton did this with many of his innovative philosophical ideas, such as ‘force’ and ‘mass’. However, this is also a feature of many of Newton’s methodological concepts: he ‘borrowed’ familiar terms and ‘massaged’ them to fit his own needs. Steffen Ducheyne has argued that Newton did this with his dual-methods of analysis and synthesis (Ducheyne, 2012: 5). Because Newton bent methodological terms to fit his needs, it is a mistake to focus too closely on the content of propositions. We should instead understand his methodology in terms of the *roles* which concepts play.

I’ll close with a final comment about the title of Newton’s *Principia*. The origin of the title is contentious. Many have taken it as an open expression of Newton’s hostility towards Cartesian science. The title, *Philosophiæ naturalis principia mathematica*, is usually recognised as a simple alteration of Descartes’ *Principia philosophiæ*. And thus been taken as a bold declaration of the anti-Cartesian bias of the work. However, D. T. Whiteside has presented an alternative view. In a letter to Edmond Halley (20 June 1686), Newton discussed the proposed title of the work:³⁶

The two first books without the third will not so well beare y^e title of Philosophiæ naturalis Principia Mathematica & therefore I had altered it to this De motu corporum libri duo: but upon

³⁶ (MS. EL/N1/55)

second thoughts I retain y^e former title. Twill help y^e sale of y^e book w^{ch} I ought not to diminish now tis yo^{rs}.

Thus, the title may have been chosen for its marketing potential—in the hopes of yielding a profit (Whiteside, 1991: 34). Whatever its origin, the title captures something important about Newton’s work. The concept of a ‘principle’ came to be closely tied up with Newton’s mathematico-experimental method. And thus, that Newton used his method of principles to lay down the foundational premises for his new natural philosophy is significant. The inclusion of the word ‘principles’ in the title of Newton’s great work might have been accidental, convenient or even vindictive. But it turned out to be entirely appropriate.

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2. **MS. EL/N1/55**

Isaac Newton, dated at Cambridge, to Edmund Halley (20 June 1686)

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