Chapter 3
Du Châtelet on Absolute and Relative Motion

Katherine Brading and Qiu Lin

Abstract In this chapter, we argue that Du Châtelet's account of motion is an important contribution to the history of the absolute versus relative motion debate. The arguments we lay out have two main strands. First, we clarify Du Châtelet's threefold taxonomy of motion, using Musschenbroek as a useful Newtonian foil and showing that the terminological affinity between the two is only apparent. Then, we assess Du Châtelet's account in light of the conceptual, epistemological, and ontological challenges posed by Newton to any relational theory of motion. What we find is that, although Du Châtelet does not meet all the challenges to their full extent, her account of motion is adequate for the goal of the *Principia*: determining the true motions in our planetary system.

Keywords Du Châtelet · Absolute motion · Relative motion · True motion · Musschenbroek · Newton

3.1 Introduction

Émilie Du Châtelet's principal work, her *Foundations of Physics*, was first published in 1740: fourteen years after the third edition of Newton's *Principia*; four years after Euler's *Mechanica*; three years before d'Alembert's *Treatise on Dynamics*; and eight years before Euler's "Reflections on Space and Time". The central theme of all these texts is the motion of bodies. More specifically, these texts intersect in the philosophical space associated with the following problem of bodily motion: given the initial motions of a collection of bodies, what will their motions be at a later time? This apparently simple problem in physics was, at the time, inextricably embedded in a web of metaphysical, epistemological, and conceptual difficulties. Among these difficulties lies the debate over absolute space, time and motion, with

K. Brading (✉) · Q. Lin
Department of Philosophy, Duke University, Durham, NC, USA
e-mail: katherine.brading@duke.edu; Qiu.Lin@Duke.edu

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the Newtonians on one side, advocating an "absolute" conception of space, time and motion, and the Leibnizians on the other, advocating a "relational" one. In this chapter, we situate Du Châtelet's account of motion in the context of the absolute versus relative motion debate. In our view, Du Châtelet's account is an important contribution to the history of this debate in the eighteenth century.[1]

One of us has argued elsewhere (Brading, 2019) that Du Châtelet modelled her *Foundations* on the textbooks of such figures as 's Gravesande (1720), Musschenbroek (1734), and Pemberton (1728). Against this background, the most striking thing about the book is its non-Newtonian elements, and especially the Leibnizian themes. As noted in the literature, these themes include Du Châtelet's versions of the principle of sufficient reason and the law of continuity, her non-extended simples ("monads"), and her Leibnizian conceptions of force.[2] What has not been studied, however, are the less obvious ways in which Du Châtelet deviated from the Newtonian textbooks that were her model, and what these tell us about her own broader philosophical position. On the topic of motion, she made essential use of resources she found in Musschenbroek. Yet, as we will see, while Musschenbroek accepted Newtonian absolute motion, Du Châtelet did not.

Du Châtelet's rejection of Newtonian absolute motion comes as no surprise to those familiar with her views on space. In Chapter 5 of the *Foundations*, "On Space", she sides with Leibniz in rejecting absolute space and endorsing a relational view of space. But those who reject absolute space must deal with Newton's arguments as to why such a notion is necessary in order for the project of the *Principia* to proceed. For this project, Newton argued, we need a distinction between absolute and relative motion. We assess the extent to which Du Châtelet has the resources to meet the demands of the *Principia* without appeal to absolute space, and therefore without adopting Newtonian absolute motion. Spoiler: she is surprisingly successful.

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[1] The history of space, time, and motion in the eighteenth century plays an important role in Torretti's work in philosophy of physics (see Torretti, 1999, and references therein). Situated between Newton and Kant, both temporally and philosophically, Du Châtelet should be of especial interest to philosophers of physics interested in this time period.

[2] See Iltis (1977) and Janik (1982) for the view that what Du Châtelet seeks to provide in the *Foundations* are Leibnizian foundations for Newtonian physics, and Brading (2019) for a different assessment, according to which the basic foundational problem Du Châtelet attempts to address is not the lack of metaphysical foundation of Newtonian physics, but the lack of an epistemically secure basis for physical theorizing. See Stan (2018) for a useful discussion of Du Châtelet's metaphysics of substance, which emphasizes its Wolffian ingredients against the received view that Leibniz is the decisive influence. See Janiak (2018) for a discussion of how Du Châtelet utilizes the resources of her metaphysics to provide a treatment of the force of gravity, which she regards Newton as failing to offer. Also see Brading (2018) for a reconstruction of Du Châtelet's solution to the problem of bodies, which is a version of a Leibnizian solution that begins with non-extended simple beings. For discussions of Du Châtelet's views on *vis viva*, see Iltis (1977, pp. 38–45), Hutton (2004, pp. 527–29), Hagengruber (2012, pp. 35–8), Suisky (2012, pp. 144–6), Reichenberger (2012, pp. 157–71), Terrall (1995, pp. 296–8), Kawashima (1990), and Walters (2001). For a discussion of Du Châtelet's exchange with Mairan on the topic of *vis viva* in relation to Kant's early philosophy of matter and body, see Massimi and De Bianchi (2013) and Lu-Adler (2018).

3.2 In Search of True Motion

The principal aim of Newton's *Principia* is to determine the system of the world: Newton sought the true motions of the bodies comprising our planetary system, and thereby to adjudicate once and for all between the geocentric and heliocentric hypotheses. A prior question required attention: what is the appropriate definition of true motion? Famously, Newton argued in favor of *absolute* motion (motion with respect to absolute space and time) and against relative motion.[3] In particular, he thought that Descartes's definition of motion as relative to other bodies must be rejected. In the scholium to the definitions in Book 1 of his *Principia* (Newton, 1999, pp. 408–15), Newton distinguished absolute from relative time, space, place, and motion, and argued that absolute rather than relative motion is needed for a physics of bodies in motion. He did so by comparing the properties, causes and effects of absolute and relative motion.

In *The Leibniz-Clarke Correspondence* (Alexander, 1956), Leibniz pushed back, rejecting Newton's conception of absolute motion and arguing for a relational conception instead. The exchange concerning absolute versus relative motion in these letters remains a source for ongoing debates today, with the balance of opinion weighing strongly in favor of absolute motion: Leibniz simply did not understand the requirements on a concept of motion adequate for the purposes of a theory of bodies in motion. This is the context for eighteenth century discussions of space, time and motion.

The focus of the debate over space and time has been primarily ontological: are space and time absolute or relative? However, as one of us has shown,[4] Du Châtelet shifts the debate into a different key. This forces us to parse Newton's arguments

[3] We distinguish true from absolute motion. In his discussion of Newton's scholium, Huggett (2012) argues that the terms "true motion" and "absolute motion" differ in meaning. We agree with Huggett that "absolute motion" means motion with respect to absolute space and time, but we disagree that the meaning of the term "true motion"—as distinct from "absolute motion"—is implicitly (partially) defined by the laws. True motion, in our view, is that motion which is proper to a body, and to assert that a body has a true motion is to assert that there is a unique motion proper to it. The next question is then whether that motion is absolute (i.e. with respect to absolute space and time) or relative (e.g. with respect to some unique privileged body or set of bodies). And so, in our view, it is motion simpliciter that is implicitly (partially) defined by the laws (for something to move just is for it to move in accordance with the laws of motion); the open questions of the *Principia* are whether that motion is true (whether there is a unique motion proper to a body), and if so, whether it is absolute. Newton's assertion in the scholium is that it is both. For further discussion of the interpretation of "absolute, true, and mathematical" see Brading (2017). Schliesser (2013) offers an alternative interpretation of the terminology for the case of time. While we do not have space to address these proposals in detail here, one advantage of the approach to the terminology that we are proposing is its consistency. Instead of "true" and "absolute" being treated differently for time as compared to motion, as they would be if we accepted both Schliesser's (2013) account for time and Huggett's (2012) account for motion, the terminology as we interpret it is uniform across time, space, place and motion.

[4] Lin, "Du Châtelet on the Representation of Space", ms.

against relational motion into three: conceptual, epistemological, and ontological. First, Newton sought to show that absolute motion is superior to relative in providing the conceptual resources necessary for a theory of true motion. Second, Newton used these resources to pursue the epistemological project of determining true motions (and, in particular, the true motions of the bodies in our planetary system). Third, Newton used the ontological status of absolute space and time to underwrite the conceptual distinctions that make the epistemological project possible.

In what follows, we discuss Du Châtelet's definitions of motion in light of this context. As we will see, she offers a threefold taxonomy of motion—"absolute motion", "common relative motion" and "proper relative motion"—using terminology she seems to have adopted from Musschenbroek. However, whereas Musschenbroek endorsed Newtonian absolute space, Du Châtelet did not, and this leads to important differences between their treatments of motion, as we shall see. We use Musschenbroek as a useful foil for explicating Du Châtelet's account of motion.[5]

With Du Châtelet's account of motion on the table, we then turn our attention to the conceptual (Sect. 3.3), epistemological (Sect. 3.4), and ontological (Sect. 3.5) challenges posed by Newton. Ultimately, the test of Newton's account of motion is its success in delivering on the main goal of the *Principia*: determining the true motions of the bodies in our planetary system. With our examination of Du Châtelet's account of motion in hand, we assess whether she has the resources to meet this demand.

3.2.1 Motion and Change of Place

Du Châtelet opens her chapter on motion (Chapter 11 of the *Foundations*) with the following definition (§211): Translations are from Du Châtelet 2009 and Du Châtelet 2018.

> Motion is the passage of a Body from the place that it occupies into another place.

By itself, this definition is neutral between absolute and relative motion; we need also a definition of "place". In the *Principia*, Newton distinguished between absolute

[5] Musschenbroek used this terminology in a series of texts in the 1730s (see, for example, Musschenbroek, 1734 and 1739). We use his *Elementa Physicae* of 1734 as our source. Our quotations and references are to the 1744 English translation, which is a translation of a later, expanded, version of the 1734 Latin original. Multiple versions of Musschenbroek's text, which are based on his lecture notes, were published under a variety of different titles. We have compared the relevant passages from the 1744 English translation to the 1734 Latin edition of *Elementa Physicae*, and also to a 1739 French translation of a similar Musschenbroek text, to ensure that the Musschenbroek materials we cite would indeed have been available to Du Châtelet during the time she was writing her *Foundations*, if not exactly as quoted here, then as close as is necessary for the points that we wish to make.

and relative place,[6] that distinction in turn being parasitic on the distinction between absolute and relative space. If Du Châtelet had adopted Newton's account of space, and thereby of place, then her definition of motion would have yielded Newtonian absolute motion. But she did not.

In Chapter 5 of the *Foundations*, immediately after her rejection of absolute space, Du Châtelet defined "place" as follows (§88):

> We call the location or the place of a Being its determined manner of coexisting with other Beings.

This is a relational definition of location or place, in which the place of a being depends (in some way) on its relations to other beings. She explains as follows (§88, continued):

> Thus, when we pay attention to the manner in which a table exists in a room with the bed, the chairs, the door, etc., we say that this table has a place; and we say that another Being occupies the same place as this table when it obtains the same manner of coexisting that the table had with all the Beings.
>
> This table changes place when it obtains another situation with respect to the same things that we regard as not having changed place at all.

This relational approach to place is consistent with her rejection of absolute space and her endorsement of a relational conception.[7,8]

Given Du Châtelet's relational definition of place, it seems we should understand her definition of motion (§211, see above) to be relational too. And this is right. But things turn out to be more complicated—and more interesting—than this simple claim suggests, as we shall now see.

3.2.2 Absolute Motion

Immediately following her definition of motion, Du Châtelet distinguishes motion into three kinds (§212): absolute motion, common relative motion, and proper

[6] "Absolute space, of its own nature without reference to anything external, always remains homogeneous and immovable. Relative space is any movable measure or dimension of this absolute space", and "Place is the part of space that a body occupies, and it is, depending on the space, either absolute or relative" (Newton, 1999, p. 409).

[7] Du Châtelet also distinguishes between location and place (§92), defining the place of a thing as the location of all its parts. She further defines situation (§93) as "the order that several coexistent but non-contiguous things maintain through their coexistence".

[8] Du Châtelet's account of space (see her Chapter 5) is extremely interesting in its own right, see Lin, "Du Châtelet on the Representation of Space" ms. Here, our interest is in her account of motion (in Chapter 11), and so we note her rejection of absolute space (as well as of absolute time, see her Chapter 6) and move on. See Hutton (2012) for a focused treatment of Du Châtelet's disagreements with Samuel Clarke, including the disagreement on the issue of space; see Jacobs (2020) for a comparative study of Du Châtelet's views on the ontology of space, extension, and bodies.

relative motion. In this, she is departing from Newton's own twofold distinction and is, we suggested above, following Musschenbroek (see his 1744, for example) in adopting a threefold terminology. However, in Musschenbroek's case, the corresponding distinctions have Newton's conceptions of absolute and relative motion as their source, for Musschenbroek endorses Newtonian absolute space.[9] He defines absolute motion as follows (§101):

> Absolute motion is the successive existence of a body in different parts of the space of the immovable universe.

Clearly, Musschenbroek is adopting a Newtonian conception of absolute motion.

At first sight, Du Châtelet seems to simply adopt Musschenbroek's definition, with the latter part of it modified to reflect her endorsement of a relational conception of space (§213):

> Absolute motion is the successive relation of a Body to different Bodies considered as immobile, and this is real motion, and properly so called.

Notice that this modification introduces terminology familiar from Descartes's definition of proper motion in his 1644 *Principles of Philosophy* II.25 (1991, p. 51):

> What movement properly speaking is. …it is the transference of one part of matter or of one body, from the vicinity of those bodies immediately contiguous to it and considered as it rest, into the vicinity of others.

In particular, both Descartes and Du Châtelet offer us a definition of "proper" motion in which the standard of rest is provided by bodies that are "*considered* as immobile" or "at rest". However, notice too this important difference between Du Châtelet and Descartes: Du Châtelet's definition relaxes the contiguity condition on the bodies that provide the standard of motion (i.e. which are considered to be at rest). Both of these points will be important later on.

It seems that Du Châtelet has offered a definition of absolute motion in terms of relative motions among bodies, rather than with respect to absolute space. How is this anything other than an abuse of words? In the *Principia*, Newton distinguished absolute from relative motion precisely because he believed that no

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[9] In the chapter preceding his discussion of motion, Musschenbroek argued for absolute space, independent of and distinct from any body or bodies, concluding in words that echo Newton's discussion of absolute and relative space in his *Principia* (Musschenbroek, 1744, §90, p. 55):

> The space of the universe is one, invisible, intangible, extended, of infinite amplitude, nor confined by any limits, homogeneous, always similar to itself, continuous, immovable, indivisible; and in which are no actual parts, but there may be accidental, which are intercepted between surfaces of bodies, and constitute relative space. Yet these cannot be seen, nor distinguished by our senses: therefore in their stead we use sensible measures, taken from the distances of bodies; and thus the parts are mensurable, though immoveable. The order of the parts is immutable, because space is one, immovable and indivisible. Moreover, it is penetrable by bodies without any resistance, containing all bodies within it, allowing them motion in and by itself.

relative motion among bodies was adequate for the purposes of physics: hence the need for introducing absolute motion as motion with respect to absolute space. Du Châtelet looks to be confused: she seems to use the words "absolute motion" to define a relational type of motion, not realizing that this defeats the whole purpose of introducing the terminology of absolute motion in the first place. In order to address this puzzle, we first need to take a closer look at what Du Châtelet has to say about relative motion.

3.2.3 Relative Motion

Du Châtelet persists with Musschenbroek's terminology, distinguishing absolute motion from two different types of relative motion: common relative motion and proper relative motion.

Consider first common relative motion. Musschenbroek writes (§102):[10]

> That is called motion relatively common, when a body carried on together with others, in respect of them keeps the same situation, and so seems to be at rest, yet together with those bodies passes through the several parts of universal space. With such a motion as this a mariner is carried, who sits at rest in his ship under sail. Or with such all things are moved that adhere to the surface of the earth, while it revolves about its own axis, and is carried around the sun. Or lastly, with such a motion a dead fish moves, which is rolled along with the stream.

Similarly, Du Châtelet writes (1740, §214):

> Common relative motion is that which a Body experiences when, being at rest with respect to the Bodies that surround it, it nevertheless acquires along with them successive relations, with respect to other Bodies, considered as immobile, and this is the case in which the absolute place of Bodies changes, though their relative place remains the same; and it is what happens to a Pilot, who sleeps at the tiller while his Ship moves, or to a dead fish carried along by the current of water.

Once again, she seems to have adopted Musschenbroek's definition, modifying it to reflect her rejection of absolute space and making explicit reference to the surrounding bodies.

In addition to common relative motion, Musschenbroek also introduces proper relative motion, writing (1744, §103):

> Motion relatively proper is a successive application of a body to the different parts of the bodies that immediately surround or touch it. With this motion all things seem to us to be carried, which in our earth we perceive to be moved.

For Musschenbroek, proper relative motion is with respect to the *immediately* surrounding bodies, and insofar as these bodies are taken to be at rest in evaluating

[10] The different word order is an artefact of the English translations being used here. Musschenbroek (1739) and Du Châtelet (1740) both use the two phrases "mouvement relatif commun" and "mouvement relatif propre".

the proper relative motion of a body, Descartes's "movement properly speaking" corresponds to Musschenbroek's proper relative motion. Yet again, Du Châtelet follows suit in adopting the terminology of "proper relative motion" while changing the content of the definition (1740, §215):

> Proper relative motion is that which one experiences when, being transported with other Bodies in a relative common motion, one nevertheless changes one's relations with them, as when I walk on a Ship that is sailing; for I change at every moment my relation with the parts of this Ship, which is transported with me.

Notice that she makes no reference to the immediately surrounding bodies and so, unlike for Musschenbroek, her definition of proper relative motion does not correspond to Descartes's "movement properly speaking".

Thus, notwithstanding the similarities in terminology, Du Châtelet's taxonomy of motion is very different from that of Musschenbroek, and the two views can be summarized as follows.

In Musschenbroek there is a primary distinction between absolute motion (which is the motion of a body with respect to absolute space and absolute time) and relative motion (which is the motion of a body with respect to other bodies). Within relative motion, there is a further distinction between common and proper. The relative motion that a body shares with some group of bodies, when moving with that group of bodies with respect to some other body or bodies, is their common (i.e. communal) relative motion. For example, the kernel and the shell of a nut may move together through the air when the nut falls from a tree, and this is their common relative motion (with respect to the air), and the kernel may also move within the shell (perhaps it has come loose and rotates within the shell), in which case the kernel has a proper motion relative to the shell, in addition to the common relative motion that it shares with the shell.

Like Musschenbroek, Du Châtelet claims a distinction between absolute and relative motion, as well as one between common and proper relative motion, but she defines all three types of motion in relational terms. In absolute motion, the reference bodies are considered immobile. In common relative motion, several bodies move together in absolute motion. In proper relative motion, a body not only moves together with other bodies in absolute motion, but also changes its relations with respect to those bodies. Therefore, despite the use of Musschenbroek's terminology, Du Châtelet has a very different account of motion. In particular, her account is thoroughly relational. What, then, is the true motion of a body, and how are we to find the true motions? In the remainder of this chapter, we examine the extent to which Du Châtelet's account is capable of addressing the challenges to a relational theory of motion posed by Newton.

3.3 The Conceptual Challenge: Properties, Causes and Effects

In his *Principia*, in the scholium to the definitions, Newton wrote (1999, p. 411):

> [A]bsolute and relative rest and motion are distinguished from each other by their properties, causes, and effects.

He then offered a series of arguments intended to show the superiority of his concept of absolute motion for the purposes of constructing a theory of matter in motion. Since Du Châtelet's account seems to admit only relative motion, despite her use of the term "absolute motion", our first question is whether her account allows her to make the conceptual distinctions that Newton argues for in his discussion of "properties, causes, and effects". With this in hand, we will then be in a position to assess whether Du Châtelet has the conceptual resources needed to carry out the epistemological and ontological work for which Newton appealed to absolute motion.

3.3.1 The Properties of Absolute and Relative Motion

We begin with the properties. It is here that Newton offers his famous nut example. He writes (1999, p. 411):

> It is a property of motion that parts which keep given positions in relation to wholes participate in the motion of such wholes. . . . Therefore, when bodies containing others move, whatever is relatively at rest within them also moves. And thus true and absolute motion cannot be determined by means of change of position from the vicinity of bodies that are regarded as being at rest. . . . For containing bodies are to those inside them as the outer part of the whole to the inner part or as the shell to the kernel. And when the shell moves, the kernel also, without being changed in position from the vicinity of the shell, moves as a part of the whole.

Newton's target here (as has been convincingly argued by Belkind (2007), see especially pp. 285–6) is Descartes, and the conflict Newton perceives between Descartes's definition of motion (as motion with respect to the immediately surrounding bodies themselves considered to be at rest) and the quantity of motion (as the product of bulk and speed) that he associates with a body (as needed for his rules of collision). In the case of the nut falling from the tree, only the shell moves relative to its immediately surrounding bodies, yet the total volume or bulk of the nut (the shell plus the kernel) contributes to the quantity of motion. How can something that is at rest (the kernel, which is at rest with respect to its immediately surrounding bodies) contribute to the quantity of motion of the nut? Newton's response is that if we define motion with respect to absolute space, rather than the immediately surrounding bodies, then the entire nut (the kernel plus the shell) is in motion, and both the kernel and the shell contribute to the quantity of motion of the nut. In short, according to Newton, a necessary condition on an adequate definition of motion is that the parts of a body in motion contribute to the quantity of motion of the whole.

Musschenbroek, in adopting Newton's definition of absolute motion, adopts a definition that meets this condition. Moreover, he makes the point about the relationship between the motion of a body and its quantity of motion explicitly (§§. 120–122, p. 65), asserting that for an extended body its motion is "equally distributed into all its parts" such that "the whole quantity of motion may be conceived alike divisible as the body, and in every part of the body it will be proportional to the magnitude of that part".

Interestingly, Du Châtelet is also able to meet Newton's condition. All parties grant that the nut is in motion (with respect to the air surrounding it, for example); the issue is the motion of the parts. Given Descartes's definition of motion, the kernel is at rest since it is at rest with respect to the immediately surrounding bodies, and so Descartes fails Newton's test concerning the motion of the parts. For Du Châtelet, however, the absolute motion of a body is not defined with respect to the immediately surrounding bodies, so she does not immediately fail Newton's test. Moreover, the kernel and the shell may be in common relative motion, even when the kernel is at rest with respect to the shell (and therefore has no proper relative motion). So Du Châtelet's definition of common relative motion allows her to evade Newton's objection. One might respond that unless Du Châtelet tells us *which* bodies we are supposed to take as our standard of rest, she cannot tell us the quantity of motion associated with the nut; this is true, but it is not the thrust of the nut example. Newton's example is intended to show that, if the immediately surrounding bodies provide the standard of rest, then the kernel must be considered as at rest even when the shell is in motion. By relaxing the condition on which bodies are used as the standard of rest, and by invoking common relative motion, Du Châtelet's relational conception of motion evades the immediate force of the nut example. In short, she has the conceptual resources to meet Newton's challenge.

It is not just the properties of motion, but also the properties of rest, that are important for Newton. He writes (1999, p. 411):[11]

> It is a property of rest that bodies truly at rest are at rest in relation to one another.

While Musschenbroek follows Newton in asserting the above property of rest (see Musschenbroek, 1744, §104) Du Châtelet once again goes her own way. She first defines rest in general, as she did for motion, before defining relative rest and then absolute rest (*Foundations*, §§220–222):

> 220. Rest is the continuous existence of a body in the same place.

[11] This claim harks back to his rejection in "De Gravitatione" (Newton, 2004) of Descartes's definition of motion. Descartes's definition allowed him to say both (1) that the Earth is at rest properly speaking (since it is at rest with respect to the immediately contiguous bodies of the surrounding fluid), and yet (2) that when considered with respect to the Sun it is in orbit around the Sun. Newton found this problematic as a basis for developing an account of planetary motion, as he argued there at length.

> 221. Relative rest is the continuation of the same relationships of the body being considered to the bodies which surround it, though these bodies move with it.
>
> 222. Absolute rest is the permanence of a body in the same absolute place, this is to say, the continuation of the same relationships of the body being considered to the bodies that surround it, considered as immobile.

This is parasitic on her definition of absolute place, which (as we saw above, and as she notes here) is a relational definition. As such (at least pending further consideration of her account of absolute place), it does not deliver the Newtonian result that bodies truly at rest are at rest with respect to one another. Du Châtelet lacks the resources by which to obtain this result.

Does this matter? In the methodology we are following here, it does so only insofar as it presents an obstacle to pursuing the project of the *Principia*: of finding the true motions of the bodies in our planetary system and thereby determining the system of the world. Do we need Newton's property of rest for this purpose? As it turns out, this condition is a sufficient condition for Newton to be able to carry through the argument of the *Principia*, but it is not necessary. As corollary VI to his laws of motion, and the twentieth century developments associated with General Relativity, make clear, the evidence Newton was working with requires a distinction between free fall and non-gravitationally forced motion, yet systems in free fall may be in accelerated motion with respect to one another. Therefore, it would be premature to reject Du Châtelet's account on the grounds that it lacks this aspect of the Newtonian account. The conceptual distinction that Newton makes turns out not to be necessary for his purposes and so, pending further investigation, it is no criticism of Du Châtelet's definition that it fails to allow for this distinction. We will not pursue this further here. Our preliminary conclusion is that Du Châtelet's failure to replicate Newton's criterion of rest is not, in itself, a problem for her definition of motion.[12]

3.3.2 The Causes of Absolute and Relative Motion

Newton writes (1999, p. 412):

> The causes which distinguish true motions from relative motions are the forces impressed upon bodies to generate motion. True motion is neither generated nor changed except by forces impressed upon the moving body itself, but relative motion can generated and changed without the impression of forces upon this body. ... Therefore, every relative motion can be changed while the true motion is preserved, and can be preserved while the true one is changed, and thus true motion certainly does not consist in relations of this sort.

[12] Rather than prematurely rejecting Du Châtelet's account for its failure to meet Newton's criterion, we should first revise Newton's criterion such that it is necessary, and then assess the adequacy of Du Châtelet's definition with respect to that. We do not pursue this here.

Musschenbroek seems to follow suit, writing (1744, §113, p. 63):

> Though true and absolute motion requires that forces should be impressed upon the bodies moving, yet relative motion may be generated and changed without force impressed immediately upon the body. It is enough if it be impressed upon such other bodies, to which the relation is made, that by their motion that relation may be changed, in which the relative rest or motion of the other consists.

Du Châtelet, though, says something different. We find a clue in her definition of absolute rest. The first part of this definition (§222) was quoted above. The second part is as follows (§223):

> When the active force or the cause of motion is not in the body which can move, this body is at rest, and this is, strictly speaking, real rest.

This indicates that absolute and relative rest and motion are distinguished by their causes. For absolute motion, the cause must be in the body itself. That this is, indeed, Du Châtelet's view, is confirmed by her treatment of the motion of bodies throughout the *Foundations*. Moreover, she is explicit about it in her discussion of place, in the same paragraph in which she defines location. She writes that for a thing to "really" change its place, the cause of that change must lie in the being itself (§88).[13] This position follows Leibniz in *The Leibniz-Clarke Correspondence* (Alexander, 1956). In the fifth letter, Leibniz re-iterates his view that Newton has not shown "the reality of space in itself", and he then says (L5: 53):

> However, I grant there is a difference between an absolute true motion of a body, and a mere relative change of its situation with respect to another body. For when the immediate cause of the change is in the body, that body is truly in motion; and then the situation of other bodies, with respect to it, will be changed consequently, though the cause of that change be not in them.

Therefore, absolute and relative rest and motion are indeed distinguished from one another, but very differently for Leibniz as compared to Newton. For Newton, changes in the state of rest or uniform motion are absolute when brought about by a force impressed on the body in question, and relative when brought about by forces impressed on other bodies. Such causes are therefore impressed (i.e. arising from outside the body rather than being internal to the body in question), and the presence and absence of impressed forces is correlated with a distinction between non-uniform and uniform motion. For Leibniz, all true motion of a body (be it uniform or otherwise) requires a force in that body. Causes of motion are therefore internal to the body in question, and the presence or absence of such forces is correlated with a distinction between motion and rest.

Musschenbroek may also have been a source for Du Châtelet, for he too follows Leibniz in asserting that when a body moves there must be a real force

[13] She writes: "Thus, in order to make certain that a Being has changed its place, and in order for this change to be real, the reason for its change, that is to say the force that produced it, must be in the Being at the moment at which it moves, and not in the coexisting Beings. This is because if we ignore where the true reason of change lies, we also ignore the reason why these Beings changed place."

in the body.[14] This may come as a surprise given that, as we have emphasized, Musschenbroek's account of motion has been standardly Newtonian up to this point. However, Musschenbroek's view on the force of bodies in motion reflects the ongoing difficulties with Newton's Definition 3 in the *Principia*, in which "inherent force of matter"—also called "force of inertia"—is introduced. The postulation of this force precedes, and in Musschenbroek's case justifies, Newton's first law of motion (see Musschenbroek, 1744, §§129–130, p. 67). It was only later that Euler (1752) insisted on reserving the word "force" for impressed force, and moved away from thinking of inertia as a force.

So for Musschenbroek, as for Leibniz, there is a real cause of motion in any body in motion, and Du Châtelet's own position is in line with this approach. Where Du Châtelet goes beyond Musschenbroek is in attempting to theorize this inherent force of body in terms of active and passive force, which she does in her *Foundations* in Chapter 8. She then puts this to use in Chapter 11 to move from her theory of motion to her laws of motion, and from there to the later chapters on the behaviors of bodies (especially Chapters 20 and 21 on statics, the equilibrium of forces, and the famous problem of *vis viva*).[15]

These concerns seem orthogonal to Newton's purposes in discussing the causes of true motions in the *Principia*. If, by changing our standard of rest, we are able to change whether or not a body moves uniformly, then the absence/presence of impressed forces is no longer a means by which to distinguish uniform from non-uniform motions, and thereby to identify true motions. So the issue of causes concerns whether or not there is a non-arbitrary standard adequate for distinguishing uniform from non-uniform motions. Newton proposes absolute space. Du Châtelet, in rejecting absolute space, must offer an alternative.

Du Châtelet's theory of absolute and relative motion, as we have explored it so far, does not provide an alternative. This is for two reasons. First, her definitions of motion are all relational, and so (pending further guidance on our choice of reference bodies) an appropriate change of reference bodies would suffice to change the motion of our target body from uniform to non-uniform. Second, her account of the force of motion internal to a body does not distinguish between uniform and non-uniform motions of that body. Instead, it distinguishes between motion and rest

[14] Here is Musschenbroek (§110, p. 62): "A moved body is transferred from one part of space into another. This transference is a real effect, which requires a real cause in the body. This must be some force moving the body. This passes from one body into another. It penetrates from the external to the internal parts of the body, not through its pores, but through the solid substance itself, and is received into every atom, though otherwise immutable, in quantities infinitely diversified from one another." He goes on (§111, p. 62): "Now we may conclude that force passes from body to body, because whatever force is lost by one, just so much is gained by the other body." And (§112, p. 62): "Is force therefore an ens physicum? Or a substance of its own kind? Or is it an idea first produced in an intelligent mind, then communicated to bodies, and passing out of one into another? None of all these can be demonstrated. It is better to acknowledge our ignorance, and that the mind is not capacitated to form a clear idea of it."

[15] For a systematic engagement with Du Châtelet's theory of forces, see Brading (2019), in particular Chapters 3 and 4.

(§225).[16] However, given her account of how one body acts on another, she *can* say at least this much: when a body changes its state of motion, its internal quantity of active force changes.

Where does this leave Du Châtelet? For the Newtonians, absolute space together with absolute time provide the resources for a conceptual distinction between uniform and non-uniform motion: a body moves uniformly when it traverses equal intervals of space in equal intervals of time. Moreover, since absolute places retain their identity over time, Newtonian absolute space provides the resources for a distinction between rest and motion. Therefore, Newtonian absolute space and time provide the resources for a distinction between the presence and absence of causes because, as will be important in the next section, non-uniform absolute motions are the *effects* of impressed forces. However, when considering the *causes* themselves, Du Châtelet has a means to distinguish, conceptually, between the causes of rest, uniform motion, and non-uniform motion.

3.3.3 The Effects of Absolute and Relative Motion

We turn our attention now to the effects of absolute motion. This has long been thought to contain the strongest argument demonstrating the superiority of absolute motion as providing the conceptual resources for a theory of bodies in motion, and so it is here that we expect to find Du Châtelet's most difficult test. Newton writes (1999, p. 412):

> The effects distinguishing absolute motion from relative motion are the forces of receding from the axis of circular motion. For in purely relative circular motion these forces are null, while in true and absolute circular motion they are larger or smaller in proportion to the quantity of motion.

There follows Newton's famous bucket example, in which he demonstrates a correlation between rotation with respect to absolute space and the shape of the surface of the water (as it recedes from the axis of circular motion), and the failure of such a correlation between the rotation of the water with respect to the immediately surrounding body (the bucket) and the shape of the surface of the water.

More specifically, the conceptual challenge being posed to the relationist is as follows. The bucket stands for any scenario in which the relative motions—no matter which body or bodies you choose as your reference body—are the same, while the observable consequences are different. These observable consequences can be thought of in two ways. First, Newton himself describes the effects of absolute rotation as the *forces* of receding from the axis of rotation. We can label this a *dynamic* reading of the bucket experiment. One can also read this scenario kinematically, i.e. without explicit reference to forces: the observed shape of the

[16] She writes (1740, §225): "the only real motion is that which operates by a force residing in the body that moves, and the only real rest is the absence of that force."

water differs when it is at absolute rest (flat) from when it is in absolute motion (curved) even though (once the water is moving at the same angular speed as the bucket) the relative motions are the same in both cases. The relationist is being challenged to show that her account of motion has sufficient resources to make these distinctions.

The bucket argument shows that the postulation of absolute space is sufficient to allow a definition of motion that supports the above correlation between forces and motions, but it does not show that it is necessary. Even if we accept that the argument succeeds against Descartes's definition of motion, which appeals to the immediately surrounding bodies for the standard of rest, we still need to investigate whether Du Châtelet, who offers a different definition of motion, has the resources to tackle Newton's bucket example.[17]

In *The Leibniz-Clarke Correspondence*, Leibniz offers only this (Alexander, 1956, L5: 53):

> 'Tis true that, exactly speaking, there is not any one body, that is perfectly and entirely at rest; but we frame an abstract notion of rest, by considering the thing mathematically.

Du Châtelet gives us just a little more (§89):

> We ordinarily distinguish the location of a body into absolute location and relative location; the absolute location is the one that suits a Being insofar as we consider its manner of existing with the entire universe considered as immobile; and its relative location is its manner of coexisting with some particular Beings.

What does it mean to consider the "entire universe" as immobile? Without an answer to this question, we cannot evaluate whether Du Châtelet has the resources to meet the challenge of Newton's bucket. We shall have to return to it below.

3.4 The Epistemological Challenge

In the final section of the scholium to the definitions in his *Principia*, Newton posed the following epistemic problem (1999, p. 414):

> It is certainly very difficult to find out the true motions of individual bodies and actually to differentiate them from apparent motions, because the parts of that immovable space in which the bodies truly move make no impression on the senses.

The problem is that the motion of a body with respect to absolute space is unobservable, because absolute space itself is unobservable. What we actually observe are the apparent motions—the motions of bodies as they appear to us, from our vantage point—and from this we can determine the relative motions. The problem we are then faced with is how to arrive at the absolute motions, since these are, for Newton, the true motions. The solution, Newton tells us, is "to draw

[17] It is widely held that Newton's absolute space posits *too much* structure (see Torretti, 1983, ch. 1, for example), but that is not the issue here.

evidence, partly from the apparent motions, which are the differences between the true motions, and partly from the forces that are the causes and effects of the true motions" (1999, p. 414). Musschenbroek too makes note of this very problem (1744, §101).

The *Principia* is a spectacular demonstration of how to solve the epistemological problem. We begin with a guess—we assume we have some sort of rough epistemic access to the presence or absence of impressed forces, and to whether motion is uniform or non-uniform, for at least some cases. We then move, using a sophisticated interplay between theory and observation, through a series of successive approximations.[18] In this way, we are able to arrive at the absolute and true motions.

Du Châtelet does not have this epistemic problem, for she does not equate true motion with Newtonian absolute motion. Nevertheless, she faces the problem of determining the true motions.

For Du Châtelet, the true (or "real") motions are those that arise from the internal force of a body (§225): "the only real motion is that which operates by a force residing in the body that moves, and the only real rest is the absence of that force." And she is explicit that it is only by discovering these forces in the bodies themselves that we can adjudicate on the problem of the system of the world; knowledge of the apparent motions alone are insufficient (see §88).

The true motions of bodies coincide with the "absolute motions", or so she seems to suggest (§213):

> Absolute motion is the successive relation of a Body to different Bodies considered as immobile, and this is real motion, and properly so called.

Similarly, for absolute rest, she writes (§222):

> Absolute rest is the permanence of a body in the same absolute place, this is to say, the continuation of the same relationships of the body being considered to the bodies that surround it, considered as stationary.

And for absolute location (§89):

> absolute location is the one that suits a Being insofar as we consider its manner of existing with the entire universe considered as immobile…

Therefore, to find the true motions it suffices to find the "absolute motions", thus conceived. How are we to proceed, and what would justify the claim that the resulting "absolute motions" are indeed the *true* motions?

Consider first her assertion that we should consider the "the entire universe" as immobile when assigning an absolute location to a Being. It is tempting to suggest that the immobile universe posited here is supposed to somehow play a role akin to absolute space in Newton, providing the immobile places to which all motions ultimately refer. However, we do not think that this was Du Châtelet's intention. Rather, we interpret her as offering an epistemic analysis of the means by and extent

[18] For in-depth discussions of Newton's scientific methodology, see Harper (2011) and Smith (2014, pp. 262–345).

to which we are able to arrive at true motions. The role of the bodies "considered as immobile" is not to approximate Newtonian absolute space, but to provide a material frame of reference useful for the problem at hand. To explain what we mean by this, we return to the main problem of determining the true motions for the system of the world.

In astronomical theorizing, the preferred material frame had long been the fixed stars: they are called the fixed stars because, as viewed from Earth, they appear to us to be mutually at rest in the night sky. Du Châtelet is clear that in practice we use the fixed stars as the standard of rest to measure the location of other celestial bodies—the Moon, the "wandering stars" (the planets), and so forth—even though the fixed stars may not be truly immobile (§91):

> We perceive that a Being has changed location when its distance from other Beings, which are immobile (at least for us), is changed. Thus, we made the catalogs of fixed stars in order to know whether a Star changes location, because we regard the others as fixed, and indeed they effectively are relative to us.

Note the phrases "at least for us" and "effectively". What these each emphasize is that, as observers on Earth, our epistemic situation is such that the fixed stars appear to be at rest relative to each other, and so we can ascribe rest to them. In other words, we use the apparent rest of the fixed stars with respect to one another for the practical purpose of providing us with a standard of rest, even though we do not know whether they are truly at rest. With the benefit of hindsight, we know that using the fixed stars as a standard of rest is well-suited for the task of determining the changing locations of celestial bodies in our planetary system. Thus, while our lack of epistemic access to the true state of the fixed stars may sound discouraging at first, as it turns out, the limitation does little harm to our theorizing. Is it just a matter of epistemic luck, one might ask, that we happen to inhabit a particular part of the universe from which so many stars appear as mutually at rest? The answer is yes: this is one instance of serendipity in the history of astronomy, one that we have been able to put to good epistemic use.[19]

Du Châtelet defines absolute motion in terms of the relation to "different bodies considered as immobile", and draws attention to the epistemic significance of the fixed stars for astronomy, which are "effectively" at rest relative to us. We suggest that these two points could be linked in a useful way by taking the motion of celestial bodies relative to the fixed stars as their *effective absolute motion*. Different from Newtonian absolute motions, which refer to unobservable absolute space, effective absolute motions refer to the fixed stars. Now we are in better place to engage with the following question: what justifies the claim that effective absolute motions are

[19] Barbour's (2001) magnificent history of the discovery of dynamics makes vivid the role of luck (both good and bad) in the observations that were available from our vantage point on Earth in the development of astronomy and the clues they provided (or masked) concerning the system of the world. See also Smith (2012) for an insightful discussion of how the method of what Smith calls "successive approximations", which lies at the heart of Newton's methodology, meets the challenge presented by the likely parochialism of our observational situation.

the true motions arising from the internal forces? In order to address this, we return to the bucket experiment.

In our view, a Du Châtelean response to Newton's bucket experiment would be as follows. First, we can infer from the different observed effects displayed by the water (including its changing shape and endeavor to recede from the axis of rotation) to the presence or absence of forces within the water. The origins of these forces lie in the bodies themselves, according to Du Châtelet's theory of forces. Second, we compare the inferred presence or absence of internal forces to the effective absolute motions of the water and bucket, using the fixed stars as our standard of rest. Finally, insofar as the forces and motions correlate appropriately, we say that the effective absolute motion (defined in terms of relations to the fixed stars) *just is* the true motion (defined in terms of the presence of forces in the bodies) whose effects we observe. Until the correlation fails, we continue to trust the fixed stars for providing us with an adequate standard of rest for the purpose of physical theorizing. However, where we find discrepancies that we cannot resolve, this may indicate the need for modifying our standard of rest.

This process is, of course, true to the *practice* of physics, for whether or not we endorse Newtonian absolute space, the apparent motions are all that we have to work with. From the Newtonian perspective, the continual modification of our standard of rest is a process of ever closer approximation to absolute space. From the Du Châtelean perspective, this continual modification brings us ever closer to the forces of bodies, from which the true motions arise, but there is no background "absolute space" relative to which those motions are "true".

In our opinion, this is a compelling analysis of the epistemic situation. However, there is a further layer to the challenge posed by the bucket experiment. The Newtonian explains the results of this experiment by appeal to the ontology of absolute space and time: absolute rotation has observable effects. More generally, absolute space and time provide the Newtonian with the resources for an ontological distinction between uniform and non-uniform motion, and this in turn both underwrites the corresponding conceptual distinction, and provides justification for the means by which the epistemological challenge is met (that is, for the claim that the observable effects of absolute motion are a guide to the true motions of bodies). Du Châtelet lacks absolute space and time, and so can appeal to no such ontological resources to back up her conceptual and epistemological analyses. We call this the "ontological challenge"; we explain it in more detail in the next section, and offer a response on behalf of Du Châtelet.

3.5 The Ontological Challenge

For Descartes, the material world is to be explained in terms of parts of matter moving around: the shapes, sizes and motions of the parts of matter are the explanatory resources to which natural philosophers may appeal. Particularly important for our purposes is the claim—widely shared, especially among those advocating "mechanical philosophy"—that motion does explanatory work.[20] As a consequence, a definition of motion will be inadequate if it yields the result that *different* outcomes are associated with the *same* motions. The bucket experiment illustrates this point: it shows that, if we begin with Descartes's relational definition of motion, we have cases where the *same* state of motion (e.g. the water at rest with respect to the bucket) yields *different* shapes for the surface of the water (flat when both water and bucket are at absolute rest; curved when both water and bucket are rotating in absolute space, as Newton would say). Therefore, Descartes's theory of motion is unable to explain the results of the bucket experiment.

Newton's claim is that, if we adopt absolute motion, then the same states of motion are correlated with observable outcomes that are the same, and when the observable outcomes differ the state of motion is different too. So, his definition of motion provides the appropriate correlations between states of motion and observations. More importantly, if we adopt the ontological commitments that correspond to his definition, so that for a body to move is for it to move with respect to absolute space and time, then different states of motion can be used to *explain* different observable outcomes. When the surface of the water is flat, this is because the water is at rest with respect to absolute space; when the surface is curved, this is because the water is rotating with respect to absolute space. This is the kinematic reading of the bucket experiment (see above, Sect. 3.3.3). We can also give a dynamical reading, in which we describe the different observable outcomes in terms of the presence and absence of impressed forces, such that the different states of motion are correlated with the presence and absence of forces. Specifically, uniform motion is correlated with the absence of impressed forces, whereas non-uniform motion involves their presence (again, see Sect. 3.3.3, above). Either way, what explains the observed effects in the bucket experiment (the shape of the water, the endeavor to recede from the axis of rotation), is the motion of the water with respect to absolute space.

For Newton, there is a real difference between uniform and non-uniform motion, and this difference, ontologically, lies in true motion being absolute: it is motion with respect to absolute space. Absolute space and time provide the ontological resources that underwrite the conceptual distinctions on which Newton relies in his pursuit of true motion.

Lacking these ontological resources, the relationist is hard-pressed to explain the results of the bucket experiment. We can summarize the challenge thus: give me a theory of motion that differentiates the scenarios in the bucket experiment, so that different states of motion *explain* the observed effects.

Du Châtelet, as we have seen, chooses the fixed stars to provide her with "effective absolute motion". This suggests a response to the bucket experiment along the following lines. We take the rest frame of the fixed stars to have not just *epistemic*

[20] This motion, as Descartes was at pains to emphasize, is not the richly varied "motion" of the Aristotelians, encompassing many different kinds of change, but strictly "local motion", that is changed of place.

significance (see Sect. 3.4), but also ontological significance. When the water rotates with respect to the rest frame of the fixed stars, the changing spatial relations result in an endeavor to recede from the axis of rotation, and the observed change in the shape of the surface of the water follows. This is a puzzling suggestion. If motion is truly relational, could we not equally use the bucket as our standard of rest, and expect the fixed stars to recede from their axis of rotating around the bucket? And even if that relational consequence is rejected, why should we take motion with respect to the distant stars as *explanatory* of such localized effects in the bucket? Is this a *causal* action of the stars on the water? Given Du Châtelet's rejection of action-at-a-distance, it seems unlikely that she would have embraced this attempted response to the bucket experiment.

An alternative response would be an endorsement of an ether theory, in which a background ether provides a standard of rest, and accounts locally for the observations in the bucket experiment. Since Du Châtelet endorsed the plenum, this might seem a more promising approach. But such a view has the following consequence: Newton's laws, by which we predict the outcome of the bucket experiment, do not hold unless an ether—to which we make no reference in applying the laws and deriving our predictions—exists. At best, this leaves the supposed explanatory role of the ether mysterious.

Neither of these options for providing an ontological underpinning, by which to explain the results of the bucket experiment, looks promising. And indeed, as later developments have shown, constructing a fully relational theory of motion is an elusive task.

We submit that Du Châtelet would have rejected the ontological challenge as misguided. Du Châtelet focuses our attention on the epistemology of the theory of motion, and in particular on the challenge of how to determine the true motions. The ontological explanation for these motions lies in the forces of bodies, and indeed ultimately in the forces of the simples from which bodies arise. It is not *motion* that is explanatory of the presence/absence of forces, but the forces of bodies that explain the apparent motions. En route to discovering the forces of bodies, we proceed via the effective absolute motions, and we are epistemically cautious: we may not have a way to arrive at a perfect correlation between effective absolute motions and the presence of forces, but Newton's *Principia* has shown us that the methodology is promising and worth pursuing, at least for now.

In Newton's *Principia*, absolute space and time underwrite the conceptual structure of true motion: they distinguish rest from motion, yield quantity of speed (as a determinate distance travelled in a determinate amount of time) and quantity of acceleration (as rate of change of speed and/or direction), and distinguish uniform from non-uniform motion. Newton's laws of motion require some, but not all, of these resources. The first law states that every body continues in its state of rest or uniform motion unless acted upon by an external force. The second law states that the quantity of deviation from uniform motion is correlated to the magnitude of the external force. Non-uniform motions of a body indicate that an impressed force is involved, the magnitude of which is correlated with the quantity of acceleration, and the source of which must be located in another body. This is the basis on which

Newton undertakes the project of determining the true motions of the bodies in our planetary system. True acceleration requires an impressed force, and the correlation between accelerations and impressed forces is the key by which to unlock the puzzle of determining the true motions. Anyone who appeals to Newton's laws can do so only to the extent that they have the resources to distinguish between uniform and non-uniform motion, and to quantify acceleration. For Newton, this is done with the ontology of absolute space and time.

The Du Châtelean response is straightforward and pragmatic: she can make these distinctions effectively, for the purposes of theorizing, and she does not require that they are underwritten ontologically in order to proceed. Indeed, to commit to an ontology of absolute space, time and motion would exceed limits of that which is epistemically warranted by the methods and results of either the *Principia* itself, or of her own methodology for scientific theorizing (see especially Chapter 4 of her *Foundations*).[21] We do not pretend that Du Châtelet herself offered this response to the bucket experiment, but we do maintain that it is consistent with her approach, and that she has the resources to meet the demands of the *Principia* without adopting Newtonian absolute motion.

3.6 Conclusions

The history of space-time theory since Newton indicates that no relational theory of space and time can provide appropriate structure for ontologically underwriting the distinction between inertial and non-inertial motion.[22] Relational attempts to explain the bucket experiment (or rotation more generally) fail because relationists lack the spatiotemporal structure to say whether or not a body truly accelerates. Since Du Châtelet offers a relational account of motion, it would seem at first sight that she is in the same tough spot as all the other relationists. Closer inspection reveals that this is not the case. Rather, she changes the focus of the debate away from ontology and to epistemology (and methodology). In so doing, she successfully meets all of the conceptual and epistemic demands placed on an account of motion by Newton's *Principia*, while also rejecting absolute space, time and motion. In our opinion, this makes her account of motion a most interesting contribution to the absolute-relative motion debate in the eighteenth century.

[21] For more discussion on Du Châtelet's methodology for scientific theorizing, see Brading (2019), Chapter 2, which argues that the problem of method lies at the heart of the *Foundations*. Also see Detlefsen (2019) for a useful study comparing Du Châtelet and Descartes's views on the use of hypothesis in science, which finds Du Châtelet's attitude toward hypothesis "considerably more modern" than Descartes's.

[22] See, for example, Torretti (1983, pp. 9–11) and Earman (1989). For a twentieth-century attempt at relational mechanics, see Barbour and Bertotti (1982).

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