Blazing: Du Châtelet as central to the first paradigm in Newtonian mechanics

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Abstract: I argue for two main points in historiography of physics regarding the significance of Du Châtelet's *Foundations of Physics* in the development of mechanics. The first is that, despite Du Châtelet calling it a textbook in the Preface, it should not be understood as 'merely' a textbook. Instead, it fits in a tradition of women involved in natural philosophy in that era using liminal publication opportunities, and to reduce some of the resistance to their publication. Even these liminal opportunities were rare and mostly available to women of very high social standing and wealth, who also happened to have supportive families or spouses, and were usually associated with some other well-known male thinker. The second point is that, even if we treat *Foundations* as a textbook, the way in which it synthesizes and refines work by Newton, Leibniz, Descartes, and others, meets the criteria given by Kuhn for the establishment of a first paradigm, which is not complete without such a definitive statement that enables the mop-up work characteristic of normal science. I conclude that by Kuhn's own criteria, he ought to have identified Du Châtelet as a key part of establishing the first paradigm in physics. She blazed a trail for others to follow.

Keywords: historiography of science; history of physics; Kuhn; Du Châtelet; paradigms

1. Introduction

One central question in history of physics involves tracing physics as we now recognize it back to its roots in natural philosophy, in order to identify the key stages of the branching-out process. This question need not have a single date or occurrence that counts as 'it' in terms of transforming intellectual work from natural philosophy into a science. At the same time, there must have been some process of branching off, insofar as physics did come to leave philosophy as a central home; and much of this can be attributed to changes in how the work takes place. Kuhn, for example, identifies the shift as one from arguing among different schools of thought, to something like mop-up work on a paradigm that is shared and in need of refinement. Once 'normal science' can take place, a field like physics has completed this branching-out. It is illuminating to consider the development of physics from the closing of the scholastic period in Europe through the establishment of physics as such as an ideal of science that it is used by philosophers, such as Kant, as something to understand as an unparalleled achievement, and used by others trying to develop new sciences, like geology, as setting the standard of what must be emulated to count as a science.

It's also becoming widely accepted that our historical perspective on what works or thinkers were genuinely influential during the development of physics has been misleadingly curtailed (inter alia, see Project Vox; New Narratives Project; Oxford *New Histories of Philosophy* series). Many 20th century historians of physics have cut out, overlooked, or simply remained in ignorance of thinkers who did not fit the mold they were looking to vindicate in their retrospective histories. The 20th century Great Man version of the birth of physics was a false narrative crafted from behind a cultural filter that precluded clearer vision on the part of writers like I. Bernard Cohen, Stillman Drake, Kuhn, and others.

This chapter will offer a meta-historiographical analysis of Emilie Du Châtelet as a key part of the transition from natural philosophy to physics as a field of science. Du Châtelet's *Foundations of Physics* has been sometimes downgraded in importance or dismissed, because of the Preface which describes the book as a textbook, written so that her son might have a better understanding of the new physics. If it is really a textbook, the idea seems to be, then it is not a substantive contribution to the philosophical discussion; it is more like a summary or even a book review of others' work. But, was it really 'just' a textbook? If not, why would she write such a Preface? And, would its status as a textbook mean that it is a less significant contribution to the new physics than the natural philosophers whose work she drew together and assembled into a coherent system? I will argue that first, the Preface situating the text as a textbook should be understood in the context of liminal publications, strategies to reduce or defuse resistance to their intellectual work, common among women in that era. Situating it as a textbook does not undermine its importance any more than correspondence, for example, should be dismissed as 'merely' a letter. Second, even if it is a textbook as we now think of those, that is itself of great note: the existence of a textbook is a central marker of a first paradigm in science, on Kuhn's influential account. I show how by Kuhn's own analysis, Du Châtelet ought to have been identified as one of the key thinkers in establishing mechanics with a first paradigm as a science.

There may not be sufficient textual or historical evidence to decide exactly how she conceived of 'textbook' and what role the Preface was intended to serve. Authorial intentions are notoriously difficult to establish and also of potentially dubious worth in evaluating the significance of a text. In the first part of this chapter, I situate the Preface to *Foundations* in a broader historical and sociopolitical context, as part of a more general maneuver that women in that era and region used in order to defuse or work around at least some of the resistance to their participation in publication on these topics by the misogyny of the day with respect to intellectual publication.

In the second part of this chapter, I make a prima facie case that the establishment of physics as a science crucially involved Du Châtelet's work. It is already uncontroversial that it took a lot of revision and clean-up work of Newton and Leibniz's original writings, along with those of others such as Descartes, to develop mechanics into a form where it could be empirically applied and tested. The mathematical and formal revisions to bring it into a more coherent and systemic form already have been credited to mathematicians such as Euler and Lagrange (see section 4). I argue for the addition of Du Châtelet to that small group whose work revising and cleaning up mechanics was central to its serving as a guiding paradigm for other practitioners to work on in a manner like that described as normal science by Kuhn.

Ironically, some of the very features of Du Châtelet and her work that contributed to historians' overlooking of her are exactly the features that count as key milestones in the establishment of the science of mechanics, according to the criteria laid out by Kuhn. Textbooks settle a commonly shared set of metaphysical commitments and basic definitions of terms, as well as laying out how to solve problems and what counts as problems to solve, which is precisely what Du Châtelet accomplished and what Kuhn uses as a central identifier of the establishment of a paradigm. She set out a coherent way to do physics that did not require settling the answers to subtle metaphysical disputes, instead collating the commonalities between these different approaches on the assumption that there was a common task at hand, to which each were directed. This common task then set the agenda for less arguing between sects, and more directed investigation into the world itself (which is a further distinctive feature of normal science with a first Kuhnian paradigm).

This chapter is the kind of project that Hagengruber (2015) urges us towards. She notes a tension at the heart of re-interpreting the historical significance of philosophers like Du Châtelet. On the one hand, there are limited impacts that women philosophers could have, given that they were often precluded from receiving education and from participating in the discussions, either in person or in print, where they could have had an impact on others. On the other hand, part of this interpretational work is to highlight the impact they did have on the discipline, which has been overlooked before. She calls this a paradox of "the inclusion of the excluded" (2015, p. 36). There is indeed a difficulty in establishing that someone who was not fully, or even minimally, allowed to be heard, nevertheless had a historically significant impact. Hagengruber does not take this task to involve showing that someone could have had an impact, had they only been allowed to have had a proper education, participate in societies, publish freely, etc. and in this I agree wholeheartedly. Certainly those counterfactuals can be entertained. Yet they are not the primary goal of

interpretational work, and need not be invoked for the meta-historiographical criticisms that the second part of this chapter lays out. Du Châtelet is an especially good case because we need not ask about what would or could have happened in terms of her impact, had things been otherwise. We already have ample evidence for actual contributions, using exactly the historiographical criteria developed for the history of physics by a hugely influential historian of that very era. So, there is a reason to draw on Kuhn's own criteria: even if one does not think he got things right about paradigms, it is damning that *by his own lights* he ought to have included her, and did not.

2. The Salon, the Chateau, the Letter-writing: liminal opportunities for intellectual work

It's well established that women were largely precluded from participating in intellectual discourse; this is true to varying extents across wide swathes of history and geography, but for these purposes, it is also well established for the parts of what is now western Europe during the early modern era, on which I will focus. Women were proscribed from participating as full members of intellectual discussions in a number of ways which of course varied from individual to individual but which comprised a headwind that affected all to some degree.

Part of this headwind was the lack of emphasis on, or even basic opportunities for, education for women. In France during Du Châtelet's era, for example, there were no schools to which girls could be sent that were comparable to the educational offerings for boys at that time.

> The problem was not simply that parents did not want to educate their female children, but that there were not even institutions available in which to do so. The convents to which young girls were often sent performed primarily a social and moral function, and only secondarily a pedagogical one. Mme du Châtelet's father had had to provide her with a battery of tutors in the early years of the century... (Goodman 1989, p. 334)

Du Châtelet had an unusual family situation in that her father valued providing her with an education in a way many other girls were not, because their families did not think it important (e.g., Goodman 1989)

It was a commonly held view at the time that women either could not, or should not, be educated to the level of or in the manner of boys and men, yet it was still an appropriate concern for a woman of that social rank that her own children receive a suitable education preparing them for

the future tasks of their social rank (for example, de Segur 1897). It is in this context that it makes a great deal of sense that Du Châtelet would have both wanted her son to have a good education in the most up to date natural philosophy and mathematics, and found that there was no single book or text to which she could direct a tutor for that education. It would have made sense that this lack of a good book synthesizing these views would have presented itself to her as a now-obvious lack, thinking about her son, in a way that it might not have seemed such a lack when she was pursuing her own interests in physics instead.

During this era in France, there was a strong tradition of salons as hubs of intellectual activity. These were hosted privately and women were centrally involved in hosting and attending, and Du Châtelet participated in and hosted salons as well (see especially Goodman 1989, Lougee 1976, Bodanis 2009). Though the emphasis on women's participation was more that of being charming companions and socialites, this also meant sometimes being adequately trained in a number of subjects such that they could at least carry a bit of conversation on these topics. "Even as new salons were opened by women to serve their own needs, they became additional centers of the growing Enlightenment Republic of Letters. The activities carried out in salons merged with the social and intellectual activity of Enlightenment" (Goodman 1989, p. 340). The openness of these conversations offered an avenue by which women who found themselves interested in these debates were able to get a glimpse into, and participate in at least some way in, the intellectual life of their society at the time, despite their being unwelcome in settings such as at the Universities or royal societies.

The salons brought together the public and private domains, bringing general discourse, where usually only men participated, into a space where women were already expected to be (Goodman 1989, especially p. 331).

> The women who led the major Enlightenment salons did not see themselves and their world in the same ways as the precieuses had. They saw their needs as women coinciding with those of the expanding group of intellectuals who were now calling themselves "philosophes," rather than with those seeking entry into the nobility and the court. Thus, while men of letters had always been part of the social matrix of the salon, by the 1760s the salon itself, as the extension of individual salonnieres, had changed to make their position central. It was thus a newly redefined social and intellectual space that was exploited by the men of the Enlightenment who saw themselves as engaged in a collective endeavor on the model of their

> Encyclopedia: a collective endeavor that needed a regular, institutional, social base (Goodman 1989, p. 332)

Thus, Du Châtelet could be exposed to ideas and the content of debates around natural philosophy by dint of her social position, even if she initially took little or no interest in it. Then, there are many ways in which both interest in, and knowledge about, these topics could grow.

> Rather than social climbers, the salonnieres of the Enlightenment must be viewed as intelligent, self-educated, and educating women who reshaped the social forms of their day to their own social, intellectual, and educational needs. The initial and primary purpose behind salons was to satisfy the self-determined educational needs of the women who started them. (Goodman 1989, pp. 332-333)

Du Châtelet was only able to accomplish her self-education during retirement to the chateau with Voltaire because of a rare combination of high social status, the kinds of tutors and equipment she could secure with her wealth, and an unusually supportive husband who facilitated this rather than standing in the way. Even with just the first two of these, lacking the third, Du Châtelet would have likely not had the opportunity for such study, work, and lifestyle.

Thus, some of the factors that enabled Du Châtelet to become as knowledgeable and skilled in her field as she did, and to have the time to make substantial written contributions to it, were outside of her direct control. This includes having been born in a family of high social standing during a rigidly hierarchical period in France; having an unusual upbringing with a father who procured tutors; having the husband that she did, who supported her work even against social stigmatization in their time; and having already produced a male heir for her husband. Other factors would have been more in her control. These include coming to have such pronounced interests in natural philosophy from salon exposure; choosing the unusual path of leaving Paris with her very much not-secret lover Voltaire; deciding that a certain kind of text would be useful for others to avoid wading through all the reading she did, to understand the new physics; having the wherewithal to follow through on all this with her publications. Her association with Voltaire may have been a mixed bag in terms of a factor within or outside of her control. It surely contributed to getting access to resources that stimulated intellectual work, and recognition by Voltaire as an intellectual partner may have eased her path to publication, but also meant having her own contributions often

assimilated to his legacy rather than hers. Yet even that very reverence towards Voltaire that credited him with her ideas also played a role in why so much of her work was preserved. For Du Châtelet, this meant a kind of intertwinement of the more private and public parts of her work: her correspondence could be both romantic (especially for her later love Saint-Lambert), and mathematical and physics-related, without clear differentiation (e.g. Tamboukou 2023), in a way that mirrors how the salon was a space that overlapped both the private and personal, as well as the intellectual and public, lives of those who participated.

The upshot is that situating this book as a textbook, and one specifically for her own child, allowed those who would have resisted original contributions to these discussions from a woman to find it less problematic than simply offering an original contribution to the debate in natural philosophy. This situating puts *Foundations of Physics* as part of a kind of liminal space. Maybe it would be better for a woman to have refrained in the first place, by such lights, yet surely it is more overlook-able as a textbook, for a son, than the publication would have been as an original contribution of her own. Yet it is also liminal because that very Preface that would have facilitated its uptake also provided grounds for dismissal of the work in terms of its original contribution. It could be labeled as 'just', or 'merely', a textbook, in historical hindsight. This sets up a tension where the only path to doing a certain kind of serious work involves making that work seem less serious, via liminal avenues for participation, such as salons and textbooks, anonymous publication, or letter-writing. And, even this liminal space for a woman engaging in intellectual work was primarily available to those with a great deal of social privilege. Women of lower social standing would not have had the free time to engage in these pursuits to this level, nor would they have been in a position to procure their own education to such a degree. And, to the extent that some of them did, we may simply never know, as no lasting texts or other evidence remain because they were not able to either publish it, or to have it collected as part of its connection to a respected male thinker.

Margaret Cavendish offers a useful comparison of liminal publication opportunities for women in natural philosophy at that time. She also had deep interests in and knowledge of the natural philosophy, combined with the kind of social privilege that allowed her access to the intellectuals of her day through social engagements. Similar to Du Châtelet, she also had extra personal privilege to facilitate intellectual work even for someone of her wealth and status, in the sense that her husband supported her intellectual endeavors and publications. This includes his not precluding her from engaging in intellectual work by forcing her to hew more to traditional gender

roles for her time and class, and also includes provision of material support for her research and writing.

Cavendish's work has been studied more as literature than in philosophy, since she is generally credited as having innovated the science fiction novel with her work *The Blazing World*, published in 1666. This book is of great note because of its ground-breaking format as science fiction of a recognizable kind (including the trope of world-traveling). It shares with Du Châtelet the situating of one's work in a somewhat alternative format (a novel For the Ladies, a textbook for a son). Cavendish preceded Du Châtelet in these debates, and it is highly likely that Du Châtelet would have been aware of this novel, even though it was published in English. They share this feature of having to trudge through disapproval of their very existence in the discussion of natural philosophy and physics in particular, and to both use alternative formats for their work.

Finally, it is worth pointing out how central the activity of letter-writing was to the participation of women, especially in natural philosophy. This also shares at least three major structural similarities with Du Châtelet's case: it is a liminal space, an alternative avenue for participation in intellectual discourse; available primarily for women of very high social standing (especially for correspondence with famous men interlocutors); and where the association with those male thinkers was largely responsible for the accessibility of the women's thought to contemporary historians. It is not an accident that the appellation 'princess' or 'Queen' goes before names like Sophia, Charlotte, Elizabeth, Caroline, Christina, and others, for whom letters survive. They had access to philosophical discourse with leading intellectuals of their day, the standing to command an audience or response, because of rank and wealth. The correspondence of princesses with the male thinkers during this era, especially Descartes and Leibniz and also Euler, Newton, Clarke, or Bernoulli, is similar to Du Châtelet's association with Voltaire in that their contributions to the field were elevated in the attention of their contemporaries, and noticed more in historical hindsight, because of the association with a prominent male thinker. This association also shaped what of their work was developed more in discussion, based on what these male interlocutors were thinking about. Of 'the two Sophies', for example, Strickland writes, "The letters of Sophie and Sophie Charlotte contain their only known philosophical writings" (2011), becoming a part of the philosophical discourse by dint of their correspondence, and the letters saved because of the renown of the male interlocutor. Princess Caroline of Wales began corresponding with Leibniz prior to departure for England, and was so central in the debates among Leibniz, Newton, and Clark that Bertoloni Meli (1999) argues that "Leibniz's 'first paper' ought to be seen as part of his

correspondence with Caroline" and that she was so involved in the debate that "later papers between Leibniz and Clarke went through Caroline... She was involved in the dispute by arguing with Clarke and even with Newton, exchanging opinions with Leibniz, and functioning as an arbiter and moderator." (p. 470).

These liminal spaces of intellectual work, like the salon, Du Châtelet's chateau retreat, alternative publication formats like anonymous publication (see Zinsser 2007, p. 166), memoirs, science fiction novels, or textbooks, were primary arenas for participation by women in the early modern era (see also Christensen 1998 for a discussion of alternative genre usage by women in France, during this era but not limited to natural philosophy). As such, it is difficult to assess, and runs a high risk of anachronism, how deeply Du Châtelet herself thought of *Foundations* as a textbook in the sense where we might now say something is 'just' a textbook on our contemporary understanding.

There is still a historiographical point to draw out about how such a Preface would have eased the way for *Foundations*, without having to directly address the question of what she 'really' thought about it. She could have had the realization that such a book would be useful, and that she should write this herself to ensure it was done to fill the kind of gap she noticed, and then continued to think of it as a textbook for her son in a way that accords more closely with the 'mere' in front of the project. And it could also be true that, having happened to have realized there was a need for this because she was considering her son's education, what she ended up accomplishing was something very different than 'merely' a textbook.

To conclude this section, Du Châtelet fits into a rich tradition of women in natural philosophy during this period whose work was often situated outside of mainstream publication options that would have been available to men (see also Shapiro 2016 for a discussion of how this shifts question about what kinds of publications count as canonical philosophical work). This larger context illuminates how we should not simply conclude that she intended *Foundations* to be a textbook as we now use that term, from the fact that she states this in the Preface.

3. Nothing 'mere' about it: *Foundations* as definitive of a system

This section will highlight a few of the key features of Du Châtelet's work on Newtonian mechanics. My goal is to focus on features that might look superficially as if they were 'just' part of a textbook, in the sense of Du Châtelet's contribution being merely that of summarizing or criticizing.

If we look at the way in which she put these conflicting systems together, it becomes clear that her 'textbook' is arguably one of the first presentations of Newtonian mechanics as we now know it. Newton's version was not there yet - it retained clunky conceptual distinctions and awkward versions of mathematical techniques. Du Châtelet refined the conceptual apparatus and combined it with ideas from Descartes and Leibniz such that the result was something that all these views shared in common, and thereby highlighted which parts were 'mere' metaphysical differences and not substantive to the mechanics. This helped to shift the kind of work that others could do on mechanics. After she highlighted the commonalities and unified them with both a metaphysical foundation and a method for doing physics (see especially Brading 2019), Du Châtelet thereby blazed a trail for other practitioners to advance mechanics by doing empirical work directed at the world, rather than arguments directed at other schools.[i]

Why might Du Châtelet's *Foundations of Physics* be considered 'merely' a textbook, and how does a contemporary understanding of textbooks underestimate her accomplishment? For reasons of space, I will focus on the Preface.[ii] Here, Du Châtelet makes several remarks that sound as if she is calling it just that, and three in particular stand out. The first, of course, is that she describes it as a book written to give her son a textbook he can use to learn about the new physics, in which he will grow more interested as he gets older, while also finding it harder if he waits to learn it all when he is older. The second is how she situates it as having removed some of the more advanced mathematics, namely, the algebra, and formulating it instead using geometry, with which her son (and others of similar ages, of course, including adults who have not studied algebra) would have more familiarity. Third, she notes that it is a collection of views that one might find in other books, but not yet collected into a single book, so that she is saving the reader time by gathering them here for a French audience, that they might get the benefit of these views without having to comb through all of them on their own. As part of this, she makes some self-effacing remarks about her own limitations, having noted the lack of such a book and taking it on herself to supply it, so that the 'truths' may be known by more readers in French.

I'll elaborate somewhat on each of these now, with an eye towards the ways in which an overly literal reading of her declaration of this as a textbook is misleading by way of involving a more contemporary, and anachronistic, understanding of textbooks. The upshot of this section will be that, textbook or no, the appellation 'merely' should be left off. Du Châtelet's *Foundations* is better described as blazing a trail that others could follow rather than having to struggle through the wilderness trying to recreate exactly what was accomplished in common by Newton and Leibniz.

Consider the first point. She offers the *Foundations* as having been assembled for her son's education, since the new physics would be important for him to know, and there were no existing resources for doing so. Here, it is useful to distinguish between her coming to realize that there was no single text that would be useful to introduce someone not yet familiar with physics to it, and setting out to fill that gap, versus writing something that merely collected others' views in a compact fashion. The statement in the Preface is, in my view, compatible with the first of these without thereby entailing the second. What may have triggered her decision to write *Foundations* was the lack of a single definitive text that laid out mechanics, and the desire to spare new pupils the slog through so many other books through which she had already waded to come to her own understanding of it. At the same time, what she actually wrote is more than simply a doxography or repetition of already known and accepted theory. She could not have 'merely' collected others' views to give an introduction to 'the' physics, because there was at that time no definitive statement of what that physics was. Indeed, the resources she drew on mostly emphasized the differences among existing views, with an eye to arguing for one over another. She had struggled through these books to come to her own understanding that there was, in fact, an identifiable common theoretical system at which these fractured views were all pointing. That in turn helped her see a much more straightforward way to communicate that coherent unified system than by reading the disunified argumentation and piecing it together on one's own. In an important sense (to be further explored in the next section), there was no definitive statement of 'the' physics because others had not yet put it all together in the synoptic way she had. What she noted was not simply a lack of a textbook, it was a lack of any common theoretical system that had both foundations and empirical testability. And what she wrote was not 'merely' a textbook, it was that common theoretical system that had been obscured by the emphasis on differences in metaphysical, and theological, grounds.

This connects to the second point, where the Preface notes that she has reframed Newton's work without the more advanced algebra, presupposing only the geometry that a student such as her son would already have. Du Châtelet herself claimed, in correspondence such as with Maupertuis (see Hutton 2004 especially), that the mathematics of Newton's own work was dense, and she took years of study herself to improve her understanding. Having done so, she could then stand in a new position and see that there could be a less arduous path to that viewpoint from which she now could see how Newton's system worked. One did not have to get there via the tortuous path laid out by Newton via possibly superfluous mathematical devices. From her vantage of having already worked it all out the hard way, she was able to see how Leibniz and Newton had achieved something very

similar in terms of the physical significance of their views. This commonality had not yet become clear because so much debate focused on the differences between their approaches. Du Châtelet was able to reformulate it, relying on both Leibnizian and Newtonian approaches, and other mathematical advances as well, in order to discern what was genuinely required. This simplified the mathematical knowledge required to understand the new physics while also showing that there was a single coherent new physics at issue, among these apparently disparate views.

For example, Smith (2021) describes Du Châtelet's version of Newton's fluxions as being a more accessible version than Newton himself developed. It incorporated some of the Leibnizian techniques as refined by mathematicians such as d'Alembert. Similarly, there was not yet a single definitive version of what we now simply refer to as Newton's Laws. Brading notes that "her laws as similar to Newton's, but differ from them in important and interesting ways. At the time, Newton's laws were not universally accepted and were given different formulations by different people, so Du Châtelet was not alone in offering her own version" (2023, p. 522). Her alteration of the mathematics in the way she describes is thus not aptly described as the kind of mere simplification for beginners that we associate with contemporary textbooks on physics. It was more like an innovative reconciliation where substantial original work was required to see how to rectify these apparently different approaches, while correcting them, to return a single cohesive view drawing on Newtonian, Leibnizian, and Cartesian work together. Her simplification of the mathematics was not simply a watered-down version.

This sets up the third point, that she is simply collecting in one place the views she herself found across multiple books. This is one where it is easiest to accidentally import a contemporary understanding of the 'just' that is too often appended to 'a textbook'. Writing a logic textbook, for example, is a much more straightforward task these days, because there are already so many out there, and the basics that a student would need to learn are already largely agreed-upon and well justified. A new textbook may tweak the details; it does not reinvent the topic. *Foundations* is not a textbook in this regard. Instead, it is a textbook in the sense of condensing and clarifying, and bringing together in a cohesive form that which had been taken to be in conflict before. "I will not write for you here the history of the revolutions experienced by physics, a thick book would be needed to report them all. I propose to make you acquainted less with what has been thought than with what must be known" (p. 118). She offers something that lifts up away from the details of individual thinkers in order to focus on what it is they were all trying to know. She re-orients the

reader towards the world as known through physics, away from physics as a kind of biographical venture about the thought of particular individuals.

This is yet compatible with *Foundations* being a textbook in a different sense, something like the first definitive statement of a view that involves definitions and techniques that practitioners can simply learn and then put to use. Her work relied on the Principle of Sufficient Reason (PSR) and Principle of Contradiction (PC) to investigate hypotheses without being led astray by them. "In presupposing [PSR], we presuppose that the universe cooperates: that metaphysically it is not capricious, and that it is therefore intelligible (at least to some extent) in terms of causes and effects. Without this, knowledge is not possible." (Brading 2019, p. 38) (see Amijee forthcoming; also Lyssy 2022, Stan 2018). Janiak (2021) argues also for conceiving of the metaphysical aspects as the required supporting foundation for the physical aspects of Newton, in order for Newtonianism to hang together: "Du Châtelet's true insight is to recognize that the new science cannot be clearly articulated without a foray into the very metaphysical topics that Newton eschewed." (p. 267) (see also Reichenberger 2020, Hecht 2020). Du Châtelet notes in the Preface that "This is one of the reasons why I have not filled this book with citations, I did not want to seduce you with authorities; and more, there would have been too many" (p. 122). This is something characteristic of a first textbook in a new field, rather than another entry into debates among thinkers, or a mere summary of existing consensus.

Brading's reading of what Du Châtelet accomplishes in *Foundations* is to tie together the metaphysical principles with their epistemological consequences. By tying these together, Du Châtelet has laid out a methodology by which it is clear how knowledge is possible, from the metaphysical side, such that these principles are not mere abstract commitments but also provide the guidance required to set up and make sense of experimentation.

> ...my point has been to emphasize that the focus of the Preface is scientific methodology. If we take Du Châtelet's text at face value, then the Preface is telling us that her principal concern is appropriate methodology for achieving knowledge in the physical sciences. ... In short, the only significant change between the two versions is the explicit introduction of the first prong of her new methodology: PSR and PC as principles to constrain theorizing. (Brading 2019, p. 31-32)

While my focus has mostly been on *Foundations*, Du Châtelet also offers a value-added, altered and improved, version of Newton's work in her translation of it (Hagengruber 2022, p. 516). She turned the translation work away from something that was about either Newton or exactly what he did in fact write, strictly speaking. Instead, this moves the debate from the metaphysical underpinnings, "to the epistemic and pragmatic challenges of pursuing Newton's goal" (Brading 2023, p. 529; see also Brading and Lin 2023).

Thus, the way in which her Preface sets up *Foundations* as a textbook should not be understood on a contemporary notion of 'merely' a textbook. She offered a definitive statement of what physics had to offer as knowledge at that point, collecting from an array of works in a variety of languages, and rendering it consistent and learnable to a French audience. In doing so, she also brought together the metaphysical disputes and highlighted how there could be a common underlying foundation that was vindicated by the role it played in supporting the methodology required to do this new physics.

4. Historiography of physics and the first paradigm of mechanics

It is not hyperbole to say that Du Châtelet received more credit for her work in the 18th century than she did in the 20th century. Even when her work was used without crediting her in the *Encyclopedia*, those reading it would likely have been aware of whose work was there. In contrast, she is not mentioned a single time in *The Structure of Scientific Revolutions*. She seems to have been deemed irrelevant by influential historians of science in the mid-20th century such as I. Bernard Cohen and Stillman Drake. *The Cambridge Companion to Newton*, edited by I. Bernard Cohen and George E. Smith, contains zero references to Du Châtelet, despite the fact that the volume is offered as about the legacy of thinkers in Newtonian physics after Newton.

In A.R. Hall's *The Scientific Revolution 1500-1800*, there is no mention whatsoever of Du Châtelet, even though there ought to have been in passages like this:

> Not until fifty years after the publication of the Principia did Voltaire's proclamation of his admiration for the profound English geniuses, Newton and Locke, begin to win adherents. ... It is perhaps paradoxical--but not unjust--that [Newton's] greatest successor was to arise not from the crowd of revered English gentlemen who were to claim Newton as their own, but in

> the person of the skeptical French mathematician, the Marquis de Laplace, whose Mécanique Céleste (1799-1825) extended in time the laws that Newton has traced in space. (Hall, p. 274)

Voltaire gets full credit for the introduction of Newtonian principles in French, and Laplace gets credit for having refined Newton's own version of the laws of mechanics. Du Châtelet is conspicuously left out.

Physics is one of the most-studied fields of science in terms of work done by historians and philosophers of science in the 20th century. Kuhn's *Structure of Scientific Revolutions* (2012/1970) focuses on it almost exclusively; his examples for the stages through which a paradigm develops are taken from his analysis of the historical trajectory of physics, from antiquity through the early modern era. While this has made it somewhat less applicable to fields such as biology or psychology, it is helpful when looking at the historical stages to which Kuhn was directly responding. And, while there are apt criticisms of Kuhn's work, there are also many practitioners in the sciences, including physics, who still use *Structure* as a kind of guide to what to expect in coming decades in their own fields.

From a historiographical perspective, it is thus illuminating to see how Kuhn's criteria and descriptions for first paradigms fit the work done by Du Châtelet. His own criteria ought to have identified her as among thinkers like Euler or Lagrange, whose work turned the disputes between Newtonian and Leibnizian schools into a first paradigm in a science, capable of guiding normal scientific research. It is especially damning to see how the very criteria that Kuhn used to identity the birth of mechanics ought to have identified Du Châtelet as crucial to this process, and he failed to do so. Even if one does not endorse those standards from Kuhn, one can appreciate how those standards were mis-applied by their own innovator.

As such, my use of Kuhn's work here does double duty. It demonstrates a plausible case for crediting Du Châtelet as one of the few select founders of physics as a scientific discipline, finalizing its branching-out from natural philosophy. This branching-out began with Descartes, Leibniz, and Newton, but which was not finished into something that could proceed on its own in a different style, with a self-sufficient paradigm that allowed for recognizably 'normal science' work to proceed. This first duty discharged by using Kuhn's work is more straightforwardly historical: there is a key part of this transition that will not make enough sense till this lacuna is filled in with better historical analyses that accord a more central role to Du Châtelet.

The second duty discharged by this use of Kuhn's work is as a kind of historiographical setting-right in sharp criticism of Kuhn's own work. It was not *simply* an oversight that led to the almost complete elimination of Du Châtelet's work from the growth of history of science as a field and the establishment of history and philosophy of science as a distinctive scholarly endeavor in the 20th century. This is why I have chosen Kuhn, despite misgivings about his work: Kuhn's work is central to contemporary history and philosophy of science, and as such, this should be rectified. It is difficult to establish with certainty that Kuhn's elimination of Du Châtelet from the history of physics in his work was deliberate or motivated by misogyny. Nevertheless, I think it is much more likely than the next likely explanation, that he simply was unaware of her work or did not have access to it. He drew on other sources in French, and other historical scholars in that time were aware of Du Châtelet. For example, Newton scholar J.E. McGuire (1969) credits Voltaire's understanding of Newtonian physics to his association with Du Chatelet. This is precisely the time period when Kuhn was writing *Structure*.

Turning now to the details of Kuhn's work. Readers familiar with *The Structure of Scientific Revolutions* will have already noticed how the previous section set up relevant features of Du Châtelet's work as displaying the features that are distinctive of a first paradigm in a new science. For example, recall how she emphasizes in the Preface, and accomplished through the *Foundations* and with her later translation of the *Principia*, that this should be a debate that is focused on the world, and what it is like. One should not be focused on whether the author is one of whom one approves, for whatever reason. "About a book of physics one must ask if it is good, not if the author is English, German, or French." (Du Châtelet 2009, p. 120). It should be on what there is to be known, not what is to be attributed to which individuals.

Prior to the existence of a first paradigm in a new scientific field, practitioners in the proto-science spend a large amount of time and word-space arguing directly against one another, and trying to establish the basics in their own definitions and terminology. The different schools will not share common basic definitions nor the most fundamental assumptions, and as such, each argues against the definitions or foundations of the other in order to argue for their own. This fails to be adequately empirical, in the sense that it is not 'directed towards the world' but at different schools of thought.

> ... the early developmental stages of most sciences have been characterized by continual competition between a number of distinct views of nature, each partially derived form, and all

> roughly compatible with, the dictates of scientific observation and method. What differentiated these various schools was not one or another failure of method--they were all "scientific"--but what we shall come to call their incommensurable ways of seeing the world and of practicing science in it. (Kuhn 2012, p. 4)

This is what we have just seen Du Châtelet move past. She developed a methodology with a metaphysical foundation such that practitioners could share those definitions, and share the methodology for how to use both hypotheses and experimentation. Recall her noting why she did not fill the book with citations. She was not primarily expounding what specific individuals thought; she was expounding what ought to be thought.

Another key marker for Kuhn of a first paradigm in a new science is the existence of a textbook (e.g. p. 19). A textbook moves past disputes between schools, and establishes a common understanding of definitions and terms. Du Châtelet offered this in *Foundations* and notes this in the Preface. Her work is among the very first to do this, and the first in the French speaking world. Simply put, on Kuhn's view, there is no first paradigm till there is a textbook by which to become inculcated as a practitioner of that paradigm.

> That is why a new theory, however special its range of application, is seldom or never just an increment to what is already known. Its assimilation requires the reconstruction of prior theory and the re-evaluation of prior fact, an intrinsically revolutionary process that is seldom completed by a single man and never overnight." (Kuhn 2012, p. 7)

This comports with Du Châtelet's description of why she thought a textbook was called for, for her son's education. The pieces of the new physics had not yet been synthesized into a single system; they were still scattered across a range of books, and often presented as conflicting.

Normal science is the clean-up work that can be done once it becomes clear that there is one consistent paradigm here (e.g. 2012 p. 24), and the apparent conflicts are merely opportunities to tighten the conceptual structure with fine tuning in order to better fit the phenomena (rather than to better suit the, e.g., theological inclinations of the thinkers).

> When the individual scientist can take a paradigm for granted, he need no longer, in his major works, attempt to build his field anew, starting from first principles and justifying the use of

> each concept introduced. That can be left to the writer of textbooks. Given a textbook, however, the creative scientist can begin his research where it leaves off and thus concentrate exclusively upon the subtlest and most esoteric aspects of the natural phenomena that concern his group. (Kuhn 2012, 19-20)

Kuhn identifies the felt need to argue for or about everything, all the way to the basic definitions of terms, part of what precedes a functional paradigm. "Being able to take no common body of belief for granted, each writer on physical optics felt forced to build his field anew from its foundations... the dialogue of the resulting books was often directed as much to the members of other schools as it was to nature." (ibid. p. 13) This is something that Du Châtelet explicitly cautions her son against. "Guard yourself, my son, whichever side you take in this dispute among the philosophers, against the inevitable obstinacy to which the spirit of partisanship carries one: this frame of mind is dangerous on all occasions of life; but it is ridiculous in physics." (ibid. p. 119)

Foundations set physics onto the track of doing normal science, instead of revolutionary, not yet settled first paradigm, natural philosophy (though, see Detlefsen 2019 for further perspective on this). Even though Newton made methodological advances, he did not do it in a way that other people could follow. She opened it up so that a community of researchers could do it in a way that advanced the science, rather than continuing the disputes between schools, or about theological implications, or about national identity. What Du Châtelet in particular contributed was to bring together these past achievements and rectify them into a single coherent system. She made clear what such work would look like to those who might have been lost in the weeds of the disputes between disciples of Leibniz or Newton. That is itself a hallmark of establishment of a paradigm: moving past the revolutionary work, of having to argue for or (re)define everything from scratch, to the kind of well-defined work with clear paths for solving problems and shared understandings of what such solutions would look like. The mop-up work, in other words, that is normal science. Neither Newton, nor Leibniz, nor others, had quite achieved this; Du Châtelet's reliance on their work, and revision and synthesis of it, turned their own accomplishments into something new that could serve as a basis for others to use for doing what would now look like normal science.

> ...'normal science' means research firmly based upon one or more past scientific achievements, achievements that some particular scientific community acknowledges for a time as supplying the foundation for its further practice.... these and many other works [incl. Newton's Principia

> and Opticks] served for a time implicitly to define the legitimate problems and methods of a research field for succeeding generations of practitioners. They were able to do so because they shared two essential characteristics. Their achievement was sufficiently unprecedented to attract an enduring group of adherents away from competing modes of scientific activity. Simultaneously, it was sufficiently open-ended to leave all sorts of problems for the redefined group of practitioners to resolve. (ibid. p. 10).

Given how closely Du Châtelet's contributions fit with the establishment of the first paradigm in mechanics as described by Kuhn in *Structure*, using this very period in physics as the generative example for his characterization of a first paradigm, this is a notable absence. Here is a clear example where Du Châtelet ought to have been included by name and has been left out.

> The *Principia*, for example, did not always prove an easy work to apply, partly because it retained some of the clumsiness inevitable in a first venture and partly because so much of its meaning was only implicit in its applications. For many terrestrial applications, in any case, an apparently unrelated set of Continental techniques seemed vastly more powerful. Therefore, from Euler and Lagrange in the eighteenth century to Hamilton, Jacobi, and Hertz in the nineteenth, many of Europe's most brilliant mathematical physicists repeatedly endeavored to reformulate mechanical theory in an equivalent but logically and aesthetically more satisfying form. They wished, that is, to exhibit the explicit and implicit lessons of the *Principia* and of Continental mechanics in a logically more coherent version, one that would be at once more uniform and less equivocal in its application to the newly elaborated problems of mechanics. (ibid. p. 33)

The reformulation of mechanical theory was not simply from Euler and Lagrange. These mathematicians also contributed, yet Du Châtelet's reformulation of Newtonian mechanics in *Foundations*, and her further reformulation and commentary in her translation of the *Principia*, was significant at that time for its reworking into a "logically more coherent version", including for those thinkers named by Kuhn.[iii]

Kuhn himself notes how historical work of this sort can be both descriptive and also sometimes normative (ibid., p. 8). "Rather than seeking the permanent contributions of an older science to our present vantage, they attempt to display the historical integrity of that science in its

own time." (ibid., p. 3) In this, Kuhn failed in his own historical task insofar as that involved any genuine historical scholarship of one of the most central examples of the transition from pre-science to normal science under a first paradigm, that of Newtonian mechanics. Even in her era, Du Châtelet received more acknowledgement regarding the significance of her contributions.

5. Conclusion

There are three different ways in which the term 'blazing' from the title of this chapter is relevant to the content here, each of which corresponds to a main take-away point.

The first notion of blazing highlights how the reading of the Preface of *Foundations of Physics* as a textbook for her child should be situated as part of a general trend where women in this era situated their work in alternative formats, at least partly to defuse some of the resistance it might have encountered had it been offered as purely original work. This use of 'blazing' draws on *Blazing World* by Cavendish, another exemplar of women publishing by situating their work as for a different audience or as something more innocuous: 'the ladies', for Cavendish; a child's textbook, for du Châtelet; letters to renowned thinkers, for princesses such as Sophia, Charlotte, Elizabeth, and others.

The second notion of blazing calls up the notion of blazing a trail. There are people who may explore some area where few if any have gone, and reach new heights there. This alone, however, is not yet something like a map, or a trail others may follow. Reporting back the way in which one went is inevitably vague when someone tries to recreate the journey. Having made it to some new mountain peak is not yet enough for others to have a path they can also follow to that peak. Instead, once it has been established that it is possible to get there, it is often someone else who then goes exploring around the area to find the best way to put in a trail by which to go from some more commonly accessible place, to the mountain peak in question. Then, they blaze this trail: leave markings along the way for others to follow, close enough and in key junctures, until enough feet have trodden it that there is a discernible foot path to follow instead ('blaze' is the term for the mark, usually carved onto a tree or stones piled in specific ways). In this metaphor, the new paradigm of mechanics is the single mountaintop that has finally been climbed by Newton, Leibniz, and Descartes. They wrote in ways that are metaphorically comparable to instructions about how to get to the same viewpoint on the mountain that they did, without realizing that they had in fact climbed the *same* mountain, from slightly different angles. What Du Châtelet accomplished was to

establish a path that others could follow to climb that same mountain. It started from the mathematical analog of a trailhead parking lot - the geometry that an audience could be assumed to have mastered already; and then marked out a path so that one could traverse from that common starting area to safely make the same ascent. She avoided some of the more treacherous and ultimately unnecessary parts of the exact route taken by, for example, Newton. This trail blazing metaphor involves Du Châtelet's assuming things like the commonality of the peak to be ascended. Despite apparent differences between them, both Leibniz and Newton had in fact ascended the same peak, not different ones, and that though they used somewhat overlapping and somewhat different paths to get there, it was making it to the peak at all that mattered, not the exact details of which traverse they took. That made it possible to find a path that others could follow safely in order to make it to the very same peak.

The third notion of blazing involves the criticism of Kuhn for failing by his own historiographical methods and criteria for identification of a first paradigm for mechanics. By his own lights, Kuhn ought to have included Du Châtelet as key to the transition from individual natural philosophers with their schools and ongoing school disagreements, to a functional field of science where multiple practitioners have well-defined problems they can solve, with well-defined and agreed-upon methods, to advance the study of nature using the system. Kuhn's failure to recognize her contribution is, by his own standards, poor scholarship. Kuhn's tedious use of 'man' throughout *Structure* is not something that can be dismissed or excused as merely standard for that time. She would have made a much better example of some of his points than the thinkers he chose instead. This looks like letting misogyny overrule scholarship, not just a mildly problematic use of gendered terminology. I note this as a criticism that is so strong, to count as 'guns blazing', that I have perhaps overstated the case. It would require a much deeper investigation into the resources that Kuhn drew on in order to write his book in order to convict him more properly of deliberate omission. One wants to make a claim here that has the correct degree of strength: neither to forgive too much poor scholarship because of lack of evidence, nor to overstate how bad the scholarship was based on the omission, without further evidence. Under the circumstances, I err on the side of the stronger criticism.[iv]

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[i] While I focus primarily on *Foundations of Physics,* similar points are made, especially with respect to the relationship between metaphysical foundations and methodology for mechanics, by Hagengruber (2011) with respect to Du Châtelet's correspondence in particular.

[ii] I have also focused on the 1740 version, as for reasons of availability; see Lin (2023) for reasons why we ought to instead look at the 1742 version.
[iii] See also Brading and Stan (2021) for a non-Kuhnian analysis of the breaking-away of physics from natural philosophy.
[iv] There isn't space to explore this connection further here, but my historiographical critique of Kuhn and use of integrated history and philosophy of science to argue for recognition of Du Châtelet as part of the founding of physics as a scientific discipline fits within the kind of historiographical project also described by Hutton (2022). It is not simply that this particular erasure should be rectified; it is also that such rectification establishes easier paths by which to extend such projects of improving history to other domains than this of women in a specific region of Europe during this specific era.