Article

Pierre Duhem's use of the *return to the sources* as a justification tool

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Abstract:

Les origines de la statique, published in 1905 by physicist and historian of physical theories Pierre Duhem, offers not only a radically new interpretation of the history of statics but also represents a milestone in the methodology of history of science thanks to a particular form of historical reasoning as deployed by the author to justify his hypotheses. This article uses a quantitative analysis of the references contained in the book's footnotes in order to study the way Duhem validated his assertions. We highlight in particular his relentless will to return to the original texts. This method is one of the reasons why Duhem's book (and more generally the Duhemian methodology) had such a lasting impact on French epistemology.

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> Les recherches que Pierre Duhem a consacrées à l'Histoire des Sciences auraient pu occuper à elles seules une vie.
> André Darbon (Darbon 1927, 499).

Introduction

The methodology in history of science has been the subject of numerous ongoing debates and discussions. It is easy to forget today that the methodological canon has evolved incessantly and that its development is due to pioneers of the discipline who laid its foundations throughout the 20th century. Georges Sarton defended the place of history of

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science as a separate discipline on its own.[3] A generation of historians and sociologists, such as Hessen, Bernal or Merton, "discovered" the role of the socio-economic context in the history of science (Lamy and Saint-Martin 2014). Mirko Grmek introduced us to the study of laboratory notes (Gourevitch 2000). Finally, Jacques Roger, among many others, called for a "historian" history of science as opposed to sociological or philosophical approaches (Roger 1995).

This list would not be complete, however, without one more important figure – Pierre Duhem, as his pervasive influence on the philosophy of science leaves no doubt (Gillies 1998; Stump 2007; Ivanova 2010). Moreover, his interpretation of the history of physics raises debates until today (Martin 1990; Biard 2004; Lejbowicz 2004). However, among all of these different perspectives on Pierre Duhem's contributions, one aspect seems to have been neglected, namely his fundamental input into the methodology in the history of science, i.e. the practice of "returning to the sources".

It is currently widely accepted that the researcher needs to allow the peers to question his/her work in order to "intersubjectively" validate it. To be trustworthy, the research results must be potentially open to discussion. This notion is essential since, as Karl Popper explains in *The Logic of Scientific Discovery*, "[t]he game of science is, in principle, without end. He who decides one day that scientific statements do not call for any further test and that they can be regarded as finally verified retires from the game" (Popper 1978, 286). This principle is generalizable to the humanities as well. The historians have to accept the need to expose their ideas to the risk of refutation if they want to take part in the epistemological "game of science". One must explain one's train of thought and choice of bibliographical references in order to submit his/her work to the judgment of the peers.

The goal of our paper is not to determine the absolute rules for good justification in the history of science but rather to describe the method and references that were presented by a historian in an argumentative process. These are the "justifying" sources that we are interested in, not the ones that were actually used in practice by Duhem. This distinction is close to that introduced by Hans Reichenbach (1891-1953), a German philosopher who was close to logical positivism, in his 1938 book titled *Experience and Prediction*:

> The well-known difference between the thinker's way of finding this theorem and his way of presenting it before a public may illustrate the difference in question. I shall introduce the terms 'context of discovery' and 'context of justification' to mark this distinction. Then we have to say that epistemology is only occupied in constructing the context of justification. (Reichenbach 1938, 6-7)

In other words, a critical evaluation of a historical work is possible only if there is an explanation of the reasoning and a presentation of the sources used, in what Reichenbach would call a "context of justification".

Pierre Duhem's practice in the art of justification is exemplary. The hypothesis of our article is that the "return to the sources" in Duhem's work is not only a rhetorical tool used to convince his opponents but a full-fledged methodological approach that profoundly marked his works. Duhem believed that the work of a historian requires a rigorous reading of the original sources in order to confront overly simplistic narratives. It is through this return to the sources that Duhem justified his new vision of science in the Middle Ages, going against the myth of the "Dark Ages". At first glance this ascertainment may seem naïve, for is it not common practice for historians to refer to the original sources? We have to mention

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[3] See, for example, the biography of Georges Sarton on the Sarton Chair website of the University of Gent: http://www.sartonchair.ugent.be/en/sarton/biography

two things. First, it is necessary to recall that history as an academic discipline did not flourish until the end of the 19th century in France, and its methodological practices were and are being constantly redefined, particularly to demark themselves from other disciplines of the social sciences (Noiriel 1990). Second, as we can see based on the examples of Auguste Comte and his disciple Pierre Laffite, who was the first chair of the general history of sciences at Collège de France, in its early days in France the history of science was less a "historical discipline" and more a part of positivist philosophy (Petit 1995). Duhem's approach, which seems almost banal today, was something novel in his time, precisely because of his methodological rigor.

In our paper we attempt to reconstruct a small part of the "Duhemian" method by using a bibliometric approach. In this sense our work joins a growing corpus of scholarly work on "scientometric portraits" that aim to present scientists through a careful study of their publication patterns (Sangam, Savanur and Manjunath 2006; Saravanan and Prasad 2012).

We take as a sample the first volume of *Les origines de la statique* published by Hermann (Paris) in 1905 (Duhem 1905) – a book that was devoted to the history of statics from Aristotle to Descartes – and one of Duhem's most marking publications. It is a compilation of a series of articles by Duhem touching upon this field of physics that appeared between 1903 and 1906 in *Revue des questions scientifiques*. (Duhem 1903) This volume does not include an exhaustive bibliography. We will analyze the footnotes in order to characterize the sources that Duhem highlighted in his seminal work on the evolution of statics.

In the first part of our article we will briefly look at Duhem's perception of the history of statics and on the general content of *Les origines de la statique.* In the second part we will present in a more detailed manner the challenges of studying Duhem's "justification" method, the raw data which we will analyze as well as our methodology of data codification. In the third and last part we will present the results of our analysis and their interpretations.

The History of Statics according to Duhem

Pierre Duhem, at the turn of the centuries, was an indefatigable defender of the history of science as a discipline. He publicly supported Paul Tannery in his attempts to establish the Chair of History of Science at the Sorbonne. Let us remark that Duhem never considered himself a historian of science as such but presented himself rather as a historian of physical and astronomical theories. Understanding the history of theories in physics and in astronomy was, according to Duhem, crucial in his job as a theoretical physicist. (Brouzeng 1987, 142) Duhem's contribution in the field of history is impressing; he wrote about one hundred articles, often compiled together in volumes (Stoffel 1996), and it would be pointless to enumerate all the books he authored throughout his life in this paper. The turning point of his career, i.e. the moment when he devoted himself to the study of history of science, can be situated at the beginning of the 20th century, in the years 1903-1904 to be more precise (Martin 1990, 349). We focus on this key transitional moment. During this period Duhem was working on the evolution of statics and became interested in the works of Jordanus de Nemore.[4] The analysis of *De Ratione* and *Elementa super demonstrationem ponderum,* of their differences as well as the use of notions such as *quantulum parvi* led Duhem to question the true contributions and limitations of the medieval sciences (Brenner 1990, 156-159). Contrary to popular opinion, a number of scholars from the period surpassed concepts stemming from Aristotelian physics.

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[4] Jordanus de Nemore, mathematician and specialist in mechanics, active in the first half of the 13th century (Grant 1973, 171)

For Duhem, science followed, in general, a continuous development. He affirms in *Les origines de la statique* that "the alleged intellectual revolutions have not been most often but slow and long-prepared evolutions" (Duhem 1905, I-IV). Modern science is a fruit of these long improvements of the medieval sciences. This idea stems from Duhem's conviction that "no human intelligence, no matter what its power or its originality, would be able to produce from scratch an absolutely new doctrine" (Duhem 1906a, 277). Thus, for Duhem, progress was possible only thanks to the contributions of numerous "precursors". This concept is omnipresent in his history of physical theories. We can see this clearly in *Les origines de la statique*, in which 14 pages are devoted specifically to a single unnamed author called "Leonardo da Vinci's Precursor" (Duhem 1905, 134-147).

In Duhem's epistemology, a theory is not reducible to a single name. For him, multiple researchers participate in the development of a scientific doctrine. Science is made possible through this collective effort and error plays an important and positive role in this process. It is an accumulation of the work of scholars that allows for the convergence of scientific theories towards "the truth", as unattainable as it may be. We can ask whether there is a point of origin of all these continuous developments in science. Duhem answers this clearly in *Le Système du monde*: "there is no absolute beginning, as far as we follow the train of thought that prepared, suggested or announced a doctrine we always come to other opinions that had been themselves prepared, suggested and announced". (Duhem 1954, 5) As Darbon explains, for Duhem science has at least three large features: continuity, finality and complexity (Darbon 1927).

Duhem's historical research illustrates, clarifies and expands his reflection in the philosophy of science. But this does not mean that to him the history of science was nothing but a tool in the service of philosophy; on the contrary, in Duhem's writing the history of science has a least three additional functions. First, it can show that the Middle Ages were not the "Dark Ages", against the widespread opinions of his times. Second, the history of science has a specific "safeguard" role, which Duhem explains in *La Théorie Physique*: "only the history of science can shield the physicist from the foolish ambitions of Dogmatism" (Duhem 1906c, 444). Finally, the historian of science plays a pedagogical role because "the legitimate, sure and fruitful method to prepare the spirit to receive a physical hypothesis is the historical method" (Duhem 1906c, 442).

In *Les origines de la statique*, Duhem affirms that statics, the field of mechanics studying equilibrium, developed continuously throughout the ages. The author tries to reconstruct the conceptual mutations, long and uninterrupted, that linked the peripatetic theories in this field to Descartes' statics. In order to do so he builds up an extensive list of scholars that worked on questions involving statics.[5] The book makes Leonardo da Vinci (1452-1519), who did not publish anything in his own lifetime, the main protagonist of this history. In fact, to Duhem it was indeed Leonardo da Vinci who erected a bridge between medieval statics and that of Girolamo Cardano. When Duhem writes about an author he often reserves a part of his work to a search for Da Vinci's influence.

However, Duhem asserts that even the greatest geniuses cannot invent a doctrine from scratch, i.e. there must be a kernel of an idea beforehand. If Leonardo da Vinci developed mechanics like no one else, there was nevertheless no "essential idea [in his thought] that wouldn't follow from the writings of medieval geometrists and, in particular, from the treaty of a great mechanician that we have named Leonardo's Precursor" (Duhem 1905, 192). According to Duhem, Jordanus' school was in the center of Da Vinci's influences. Da Vinci constructed his statics by either following or rejecting Jordanus' assertions. Even if

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[5] This list includes Aristotle, Euclid, Archimède, Jordanus de Nemore, Blasius of Parma, Leonardo da Vinci, Tartaglia, Girolamo di Cardano, Guido Ubaldo, Galileo Galilei, Simon Stevin, Gilles de Roberval and René Descartes.

a large number of problems in statics was discussed in the middle of the 16th century, the solutions that were supposed to form the corpus of the theory were still tainted with many errors during this period. It was the end of the 16th and the beginning of the 17th century that allowed to separate the wheat from the chaff and to find out, according to Duhem, what had already been invented before. Duhem successfully retraces, in the first volume of *Les origines de la statique*, the continuous evolutions of theories on statics, from their Greek roots to the independent science of Descartes. He strongly argues that "in science, there is no spontaneous generation" (Duhem 1905, 156). Now that we have exposed the broad lines of the history of statics according to Duhem we can study the way he used the footnote to justify his arguments.

Pierre Duhem, *Les Origines de la Statique* and the Footnotes

The codification of sources as used by Duhem in *Les origines de la statique* is facilitated by the fact that the use of references and footnotes was already normalized at the end of the 19th century (Grafton 1998, 171). We will focus on the nature of the "justifying" sources and on how Pierre Duhem used them at the turn of the centuries – the key moment of his career. The first question we ask is: Does he use translations or the original publications? The other questions that follow are: Does he prefer primary or secondary sources? Does he quote the body of the text or does he reformulate the ideas of the author? Does he focus on bibliographical and biographical information or rather on concepts? Are the references used to support Duhem's own ideas or, on the contrary, to present different points of view? Is there any variation in the number or type of sources used depending on the topic discussed? Does Duhem have a favorite author?

In order to answer these questions, we undertook an analysis of the footnotes and the bibliographical references they include in the first volume of *Les origines de la statique* (1905). Working on the footnotes of this volume, which does not have a bibliography, allowed us to study the spatial and temporal distribution of the references in the book and to construct a kind of topography. This analysis allows to observe variation, depending on the periods studied by Duhem, of elements such as the number of citations by page or the type of references that were used. Moreover, the 467 footnotes in the volume constitute a corpus large enough to make our analysis statistically significant. Duhem occasionally mentions in the body of the text itself books without giving any references in the footnotes. We decided to exclude these references from our study because, when using the quantitative method, it is important to compare only that what is comparable (Lemercier and Zalc 2008, 19). And it seems to us that the references in the footnotes and those in the text convey different types of information, e.g. on page 60 Duhem mentions "the oversimplified dynamic coming from Galileo's Discorsi" in the text. In the footnote on the same page (but not one associated with the citation above) he writes: "*Les Manuscrits de Léonard de Vinci*, publié par Ch. Ravaisson-Mollien; Ms. F de la Bibliothèque de l'Institut, fol. 84. recto. Paris, 1889". We can clearly see that the structure and information that these two examples transmit are different and hardly comparable. As a consequence, our corpus of study will be limited only to references in the footnotes.

Constitution of data

We have to codify all of the information to obtain statistically exploitable data in order to answer the above-mentioned questions. Our codification task is done via three phases for each footnote, in a spreadsheet. In the first phase we attribute a specific number to each

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footnote and we gather the "structural" data, i.e. the page of the footnote and the footnote's number. In the second phase we extract comments as well as bibliographical information, e.g. the author, title, publication date, translator's name and the name of the editor. Finally, the third phase is structured around seven questions, which we will call "steps" and which we ask regarding each footnote. To simplify our analysis, these steps have only two possible answers (0 or 1). Using this binary code allows us to assemble the totality of information in a single spreadsheet and facilitates the statistical analysis. Our approach, as all quantitative methods, results in a kind of reductionism; this simplification is nevertheless necessary for statistical treatment of data. (Lemercier and Zalc 2008, 41-42) We will now describe each of the seven steps.

1. What is the form of the footnote? *Reference* (1) or *plain comment* (0)?

A footnote is considered a *reference* if it contains at least one bibliographical reference, with or without a comment. It is considered a *plain comment* if the footnote does not have any reference.[6]

This step is necessary to warrant the consistency of our results. Footnotes without references are not supposed to be taken into account in our statistical calculations.[7] For the next six steps we will exclude spreadsheet lines with (0) in this column by attributing them the "/" value.

2. Is the reference in the footnote a *plain reference* (1) or an *annotated reference* (0)?

A footnote is considered a *plain reference* when it contains at least one bibliographical reference and no comment. This is the case for the footnote on page 13: "*Libri, Histoire des Sciences mathématiques en Italie, depuis la Renaissance des Lettres jusqu'à la fin du XVIIᵉ siècle.* Paris, 1840, t. III, p. 11". (Duhem 1905, 13, note n°1) A note is, on the other hand, an *annotated reference* if it contains a commentary by Duhem beyond the reference, e.g. "This pamphlet is also found in the following edition: Le Opere di Galileo Galilei, ristampate fedelmente sopra la Edizione nazionale con approvazione del Ministerio della publica Instruzione. vol.1 (seul paru). Firenze, Successori Le Monnier 1890". (Duhem 1905, 237, note n°2)

3. Is the reference in the footnote *translated* (1) or *not translated* (0)?

A reference is considered *translated* if the book cited was translated by someone other than the author. This category includes bilingual texts.[8] On the other hand, the reference is considered *not translated* if the footnote includes only the reference to the original version of the text.[9] This second category includes authors who translated their own books.

4. Is the footnote associated with a *citation* (1) or a *reformulation* (0)?

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[6] For example, the second footnote on page 248 that explains the notion of *impeto*: "this word has here the same sense as in the works of Leonardo da Vinci; it is close to the name *force vive* as used by Leibniz" (Duhem 1905, 248, note n°2).

[7] The choice to exclude these footnotes is justified in part 3 of this article.

[8] For example, the French edition of *Des Manuscrits de Léonard de Vinci* was translated by Charles Ravaisson-Mollien but also includes the original version of the text (Leonardo da Vinci 1881).

[9] To authors from Antiquity a manuscript in Latin will be considered *not translated* (e.g. Aristotle's manuscripts in Latin).

A footnote is a *citation* if in the text associated with the note Pierre Duhem textually cites his source by using quotation marks. It is considered a *reformulation* if in the body of the text Duhem uses an indirect style.

5. Is the reference book a treaty in *physics* (1) or in the *history of physics* (0)?

A reference is in *physics* if it was written by a scholar from times contemporaneous to or preceding the period which is discussed in the body of the text, e.g. when Leonardo da Vinci is referenced in the chapter devoted to Girolamo Cardano (Duhem 1905, 41, note n°2). A reference is considered the *history of physics* if it concerns a book whose author came later than the one studied in the chapter. This category includes books in epistemology, dictionaries and biographies.

6. Is Pierre Duhem in *opposition* to (1) or in *favor* of (0) the theses of the author he discusses.

A footnote is considered *in opposition* if in the body of the text associated with the footnote or in the footnote itself Pierre Duhem opposes the author's point of view or criticizes his translation, e.g. note n°1 on page 57, where Duhem criticizes the translation by Richard Leblanc:[10] "Cardan, *Les Livres de la Subtilité*, traduis de latin en françois par Richard le Blanc. Paris, l'Angelier, 1556, p. 339. The citations that follow are translated directly from the Latin text, they do not come from le Blanc's translation, rather obscure in this passage" (Duhem 1905, 57, note n°1). This category does not include the "scientific" errors as demonstrated by Duhem. In fact, his goal was to retrace the history and evolutions of an idea, not to correct the errors of the past. If this is the case, then there is no "opposition" to the given scholar's point of view, strictly speaking. The footnote is considered *in favor* if it supports or justifies Duhem's assertion.

7. Is the footnote of a *bibliographical/biographical* nature (1) or of a *conceptual* one (0)?

A footnote is considered *bibliographical/biographical* if the reference or passage that is associated with it provides new information on the life, edition or circulation of the books of a given author. It is considered *conceptual* when the reference, or a part of the text corresponding to the footnote, develops philosophical or physical questions.

Now that we have established our corpus and described our method, we can focus on the extraction and analysis of the data we possess.

Results and Interpretations

We codified data extracted from 467 footnotes distributed over 360 pages of the first volume of *Les origines de la statique*. Among these, 37 (or 7.9%) were *plain commentaries* that will be excluded from our statistical analysis. In the remaining notes we found 454 bibliographical references that we will make use of. We constructed our dataset by applying the method described in the second part of the article to these 454 references.

The Scope of Justifying Footnotes in Duhem's Work

Before starting the interpretation phase, it is crucial to verify whether the footnotes constitute a justification tool in *Les origines de la statique* at all. We will analyze the table of average values obtained by our method.[11] A general pattern shows that the footnotes include

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[10] Richard Leblanc (1510-1580) was a French writer known for his works on cooking.
[11] Cf. Appendix 1 "Table of Average Values".

at least one bibliographical reference.[12] Their most important function in this volume is to give references; nevertheless, they are not limited solely to this purpose, as ca. 15% of all these references are connected with some sort of commentary, either critical or descriptive.[13] This is the case of the already mentioned note 1 on page 57, where Duhem questions the quality of the translations done by Richard Leblanc. Overall, however, this use of footnotes remains limited.

The study of average values obtained in phase 6 of our analysis (*opposition* or *support*) of the entire volume reveals that the references usually support Duhem's arguments.[14] Only occasionally does Duhem use the footnotes to mention theories that are opposite to his own, e.g. in a note on page 8 he comments on a proposition made by J.L. Lagrange:[15] "At one time it was fashionable to consider the science of Aristotle and his commentators as void of substance; this prejudice was sufficient to make much of the valuable intellectual progress incomprehensible; thus in a historical introduction, indubitably beautiful, that opens *Mécanique Analytique*, Lagrange wrote what follows about the Principle of Virtual Displacements: '(…) Guido Ubaldi is most likely the first to have observed it in the lever or in mobile pulleys'". We see in this example that Duhem tries to present and justify his criticisms. He does not attack without reason the ideas of another author. In general, he prefers to develop his own ideas instead of criticizing others, and he points out that, as for the history of statics, the existing works were "limited in number; (…) and most of the time rather brief and not very detailed" (Duhem 1905, I). These two facts confirm his genuine will to justify the arguments through the references in the footnotes of the first volume of *Les origines de la statique*. Our approach is validated; hence we can now establish a profile or a framework for how Duhem typically used footnotes. Let us calculate the mean values for the entire volume of each of the seven criteria enumerated above.

As we have demonstrated, the footnotes are most often used to justify an argument,[16] i.e. they take the form of bibliographical references supporting an idea, and only rarely does Duhem add a commentary to them.[17] They are associated in similar proportions with the citations or the reformulations.[18] The footnotes most often refer to publications in their original languages.[19] We can also mention the correlation that exists between the types of sources and the type of information.[20] The references used by Duhem give, in general, information on the theories on statics of a given author, so they are most often written by scholars from the period that was discussed by Duhem.[21] We see here again Duhem's "return to the sources". To illustrate a typical case of the use of footnotes in the first volume of *Les origines de la statique*, let us have a look at the chapter devoted to Gerolamo Cardano and take as an example this note: "Cardan, *Opus novum,* Propositio LXXII : *Proportionem ponderis*

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[12] Cf. Appendix 1 "Table of Average Values", 92% of the footnotes have at least one bibliographical reference.

[13] We mention here the case of references with comments. We will also study *Pure Comments*, which represent ca. 8% of the footnotes.

[14] Cf. Appendix 1 "Table of Average Values", 95% of references are used to support the argument.

[15] Joseph-Louis Lagrange (1736-1813) was a French mathematician and physicist of Piedmontese origin. He was one of the founders of analytical mechanics and one of the fathers of variational calculus.

[16] We preferred to use the table of mean values instead of studying the frequencies for each phase combination. In fact, the results, even if similar, would be more difficult to exploit in this case.

[17] Cf. Appendix 1 "Table of Average Values", 92% of the footnotes contain at least one bibliographical reference, 95% of references support Duhem's arguments, and 85% of references are not commented on.

[18] Cf. Appendix 1 "Table of Average Values", 49% of the references are associated with a citation.

[19] Cf. Appendix 1 "Table of Average Values", 71% of the references are not translated.

[20] There is a correlation coefficient of -0.51 between the phases "physics or history of physics" and "bibliographical/biographical or conceptual". This means that the sources in *Physics* bring, in general, conceptual information, while the sources in *history of physics* bring biographical or bibliographical elements.

[21] Cf. Appendix 1 "Table of Average Values", 75% of the references are in *Physics*, while 61% give conceptual information.

sphaerae pendentis ad ascensum per acclive planum invenire. Basileae, 1570, p. 63" (Duhem 1905, 50, note n°1).

The above contains a reference with no comment attached and cites a book written in Latin – the language of Cardano's publication. It is associated, in the body of the text, with a reformulation of Cardano's ideas: "In *Opus Novum*, it is proposed (1) to determine the weight of a mobile sphere on an inclined plane, the weight he [Cardano] believes is, according to the Principle of Dynamics universally admitted at his times, proportional to the speed with which the sphere left on its own will descend on this plane" (Duhem 1905, 50, note n°1). We can see that Duhem extracts theoretical information about Cardano's statics from his book; hence the note subscribes itself perfectly to the Duhemian canon of justification.[22] However, once this framework is described it would be reductive if we limited ourselves to it since there can be "local" variations of it depending on the topic discussed or the approach as used by Duhem. We will now proceed precisely to a study of these variations.

A "Rational" Use of the Translated Books

We can, for example, have a detailed look at one of the first questions we asked: the place of translations in the footnotes. Pierre Duhem's mastery of different languages leaves no doubt: in the first volume of *Les origines de la statique* he cites publications in German, Italian, Latin, Ancient Greek and, of course, French. Hence, the use of translated sources is an interesting topic. Even though they remain a minority among the references, we can, however, try to determine the particular reasons for their use. The most important reason that made Duhem cite the translated publications is self-evident, i.e. when he did not speak the original language of the publication (e.g. he did not speak Arabic or Flemish). In *Les origines de la statique*, he refers to translated books when he has no alternative. We can find the perfect illustration of this situation in the twelfth chapter of the book. This part is devoted to S. Stevin (1548-1620), who wrote his works in Flemish. Only once does Duhem refer to texts in the original version (Duhem 1905, 264); in the rest of the chapter, readers are referred to the Latin translations by W. Snell (1580-1626): *Hypomnemata mathematica* (1605).[23] Even though Duhem mentions a later French translation (1634) in the first note on page 264, he does not use it to justify his arguments. This clearly supports, again, the will of "returning to the sources", which is omnipresent in Duhem's work: when he is not capable of quoting the original book he refers to the oldest translation he can find, in this case to the one by W. Snell.

One case seems to detract from this general rule though: we notice it almost exclusively in references to Gerolamo Cardano. In fact, the first volume of *Les Origines de la statique* counts 24 references to this author who published in Latin, but ca. 42% of them refer to the French translation by Richard Leblanc of *De subtilitate rerum* (Cardan 1556). It seems that Duhem had access to this text in its Latin version because he refers to it three times and writes in the fourth note on page 39 (continued on page 40): "Beyond the editions that have been cited we also found in Bordeaux, at the Municipal Library and at the University Library (…) two other Latin editions of *De Subtilitate*" (Duhem 1905, 39, note n°4). Moreover, he criticizes the quality of the translation by Richard Leblanc which he qualifies as "*fort obscure*" (Duhem 1905, 57, note°1) in certain passages, and he even corrects Leblanc's errors (Duhem 1905, 48, note n°2). It is nevertheless difficult to determine the reasons behind this unusual choice of references in the case of Cardano.

When speaking of references to the translated texts, it is interesting to point to four oddities in our table of average values.[24] In fact, when we analyze the percentages of

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[22] In the first volume of *Les origines de la statique*, 122 references (27%) follow exactly this profile.
[23] A total of 22 out of 23 references to Stevin in Chapter XII refer to this book: S. Stevin & W. Snellius, 1605.
[24] Cf. Appendix 1 "Table of Average Values".

references including translated sources, these remain relatively low for most of the chapters (oscillating between 0% to 45%), with four major exceptions (Chapters II, IV, VIII and XII). In Chapter XII (*Simon Stevin 1548-1620*), the percentage goes up to 89%, which is easy to understand because Stevin is the author to which Duhem refers continuously throughout the chapter. The particularity of Chapters II (70% of translated sources), IV (93%) and VIII (90%) can be explained by the fact that in these chapters Duhem often refers to bilingual texts. In fact, *Les manuscrits de Léonard de Vinci*, translated by Charles Ravaisson-Molliens (Léonard De Vinci 1881), is a bilingual edition with a manuscript, its transcription and the translation. Once again, Duhem shows the consistent practice of returning to the original sources whenever this is possible.

Leonardo da Vinci, the Central Actor

In the first part of the paper we mentioned the central place that Leonardo da Vinci occupied in the history of statics according to Duhem. The French physicist states, in the first volume of the *Les origines de la statique*, that Leonardo da Vinci was the author responsible for "a development on a marvelous scale" of theories in the field of statics (Duhem 1906a, 193). We can ask ourselves whether this particular status is corroborated by our data analysis. In order to do so we examined the references to Leonardo da Vinci; 76 out of 454 references presented in the footnotes of the volume (ca. 17%) refer to the writings of Leonardo. This value is even more important if we compare it with the number of references to the seven most referenced authors in the footnotes. With 220 references, these authors represent almost half (48.5%) of all references used by Duhem.
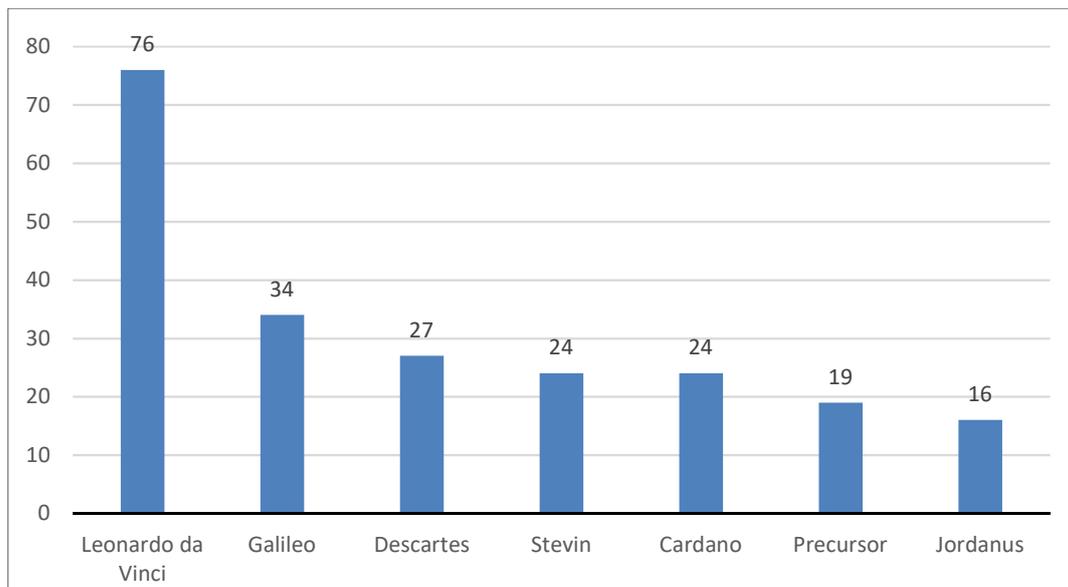

Figure 1 Number of references of the seven most referenced authors

We clearly see in the plot that Leonardo da Vinci is the most referenced author in the footnotes, e.g. Duhem makes 2.2 times more references to da Vinci than to Galileo, who is second on the list. This shows the importance that Leonardo da Vinci had to Duhem in the history of statics. The French physicist deepened his interest in the works of the Florentine maestro in the book in three volumes titled *Études sur Léonard de Vinci* (Duhem 1906b; Duhem 1909; Duhem 1913). Let us also note that if we exclude da Vinci from our analysis the number of references to the other key authors in the history of statics until Descartes remains

almost uniform. More generally, in Figure 1 we can see a new illustration of the Duhemian will to "return to the sources". The seven most represented authors (Leonardo da Vinci, Galileo, Descartes, Girolamo Cardano, Simon Stevin, Leonardo's "precursor" and Jordanus de Nemore) are scholars who played, according to Duhem, an important role in the evolution of doctrines on statics. No historian of science or later commentator is present among these seven names.[25] These results seem coherent with Duhem's typical use of footnotes: there are works of physicists throughout the ages that are in the heart of the Duhemian justification, not works of their later interpreters and commentators.

Examples Outside the Framework

We established the model type of reference for the first volume of Duhem's *Les origines de la statique*. Before concluding, we should mention, however, examples outside this baseline framework, such as the *plain comments*, which we have excluded from our statistical analysis.[26] There are 37 pure comments in the volume, which represents 7.9% of the footnotes. Their distribution is uniform, there are no significant variations and their role is, first and foremost, to explain and to criticize. Of the 37 footnotes, 8 are remarks on the quality of a translation, 17 are theoretical explanations, 6 constitute complementary bibliographical or biographical information and 6 are references to the first volume of *Les Origines de la statique* itself.

Conclusions

Duhem, in his works on the history of statics until Descartes, wanted to oppose the "classic" history of science from his times (Duhem 1906a, 278). He affirmed that the mainstream narrative was "falsified by prejudice and truncated by voluntary simplifications" (Duhem 1906a, 278). In the secular Third Republic, Duhem contested the republican dogma which considered the Middle Ages as a period of obscurity when the progress of science had supposedly stopped. He thought that scientific progress was the fruit of a "continuous action of Wisdom", or of "Providence", and that nothing could stop it (Duhem 1906a, 290). As a consequence, he tried to prove that statics had developed continuously throughout the Middle Ages. To fulfill this goal, he had to "refer to contemporaneous sources, to manuscripts" (Duhem 1905, II). We see in this quotation, once more, the will to return to the sources, which is one of the reasons for Duhem's notoriety. For Duhem, the use of the "return to the sources" was a general working method in the "context of discovery". But, as our paper demonstrates, he also used it as an argumentative tool in the "context of justification".

Duhem showed, via his example, that historians should refer to scientific works in versions that are as close to the original as possible. When he argued that Leonardo da Vinci had been inspired by the works of Jordanus de Nemore he explained in detail all the links that he could determine between the theories of the two scholars and supported his arguments by using numerous references to their manuscripts. Through this justification, based on the omnipresence of the original sources, Duhem laid a fundamental principle: a future historian wishing to contest Duhem's affirmation would have to "go through all the manuscripts relative to statics" first (Duhem 1905, II). Finally, this statistical study of the

[25] The philologist Maximilian Curtze (1837-1904, thirteen references in the footnotes) and the mathematician and historian Guillaume Libri (1803-1869, 9 references) are those who appear most often.
[26] We have already explored the "annotated references", the goal of which is most often to be critical or descriptive.

footnotes clearly showed that for Pierre Duhem it was preferable to refer to writings that had not been translated or edited. This approach indicated that Duhem did not consider a translation or a re-editing as neutral towards the text.

Duhem was rigorous in his approach, and his choice of sources was always coherent when he discussed the physical theories of an author. Rarely did he deviate from the "return to the sources" approach; this was, for example, the case regarding the biographical elements that Duhem took from later works, but we should not forget that Duhem was first and foremost a historian of physical theories. Thanks to our systematic study of the footnotes, we can conclude that for Pierre Duhem a return to the original sources, as close as possible to the theme he studied, was not a mere rhetorical trick but a full-fledged justification tool that he used consistently.

Our article, beyond its theoretical conclusions, also indicates a few novel methodological elements based on quantitative approaches that may be useful in establishing more pertinent Scientometric portraits. It might be interesting to extend the application of this method to other historians of science in the near future.

Acknowledgment:

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Appendix

Appendix 1: Table of Mean Values

Chapter	Reference (1) or Plain Comment (0)	Pure Reference (1) or annoted Reference (0)	Translated (1) or Not translated (0)	Citation (1) or Reformulation (0)	Physics (1) or History of Physics (0)	Opposition (1) or Support (0)	Bio/Bibliographical (1) our Conceptual (0)	Number of Pages
Chapitre I : Aristote et Archimède	1	0,75	0,25	0,5	0,75	0,25	0,13	8
Chapitre II : Léonard de Vinci	0,94	0,97	0,7	0,73	0,73	0	0,2	21
Chapitre III : Jérôme Cardan	0,85	0,9	0,45	0,45	0,76	0,03	0,34	18
Chapitre IV : L'impossibilité du mouvement Perpétuel	0,79	0,87	0,93	0,87	1	0,07	0	9
Chapitre V : Les Sources Alexandrines de la Statique du Moyen Âge	0,95	0,87	0	0,32	0,21	0,22	0,79	37
Chapitre VI : La Statique du Moyen Âge Jordanus de Némore	0,96	0,77	0	0,23	0,28	0,19	0,95	26
Chapitre VII : La Statique du Moyen Âge (suite) L'école de Jordanus	0,98	0,78	0	0,15	0,76	0,00	0,52	32
Chapitre VIII : La Statique du Moyen Âge et Léonard de Vinci	0,89	0,9	0,9	0,74	0,98	0,00	0,02	38
Chapitre IX : L'école de Jordanus au XVIe – Nicolo Tartaglia	0,94	0,75	0,25	0,56	0,88	0,00	0,44	16
Chapitre X : La Réaction contre Jordanus : Guido Ubaldo – Benedetti	0,91	0,81	0,12	0,44	0,91	0,02	0,26	27
Chapitre XI : Galileo Galilei (1564-1642)	0,95	0,83	0,06	0,43	0,89	0,03	0,35	27
Chapitre XII : Simon Stevin (1548-1620)	0,82	0,93	0,89	0,32	0,96	0,00	0,11	27
Chapitre XIII : La Statique Française – Roberval	0,92	0,82	0	0,59	0,91	0,00	0,43	37
Chapitre XIV : La Statique Française (suite) – René Descartes (1596-1650)	1	1	0,04	0,92	0,96	0,00	0,36	26
Notes A, B, C	1	0,5	0,13	0,25	0,63	0,00	0,38	6
Average Values (basing on the number of pages)	0,92	0,85	0,29	0,49	0,75	0,05	0,39	23,67