Each book its own Babel

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DOI:
10.33612/diss.849175103

university of groningen

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Conceptual Unity and Disunity in Early Modern Natural Philosophy

PhD Thesis

to obtain the degree of PhD at the
University of Groningen
on the authority of the
Rector Magnificus Prof. J.M.A. Scherpen
and in accordance with
the decision by the College of Deans.

This thesis will be defended in public on

Thursday 21 December 2023 at 11.00 hours

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Acknowledgements

Science is a collaborative endeavor. Although this dissertation is a product of my own mind, it exists within a broader context that gave it much of its shape. Most importantly, the dissertation operated within the broader European Research Council-funded project *The Normalisation of Natural Philosophy: How Teaching Practices Shaped the Evolution of Early Modern Science*. I have used a corpus that was generated at the start of the above-mentioned project as the basis for much of my investigations. I have co-developed methods for analyzing and modelling this corpus that went both into this thesis and into the project as a whole, and have worked together with the team to ascertain that the quality of the digital transcriptions was high enough for specific kinds of research.

In spite of this extensive co-operation, I have generally followed my own intuitions in shaping the thesis within this broader context. I would like to thank my supervisors, Andrea Sangiacomo and Raluca Tanasescu, first and foremost for their patience in dealing with the direction I gave to my research. It took me a while to select the right methods, the right questions and the most appropriate framing. I found myself, at some point, having to discard previous work and had to resist walking certain well attested routes of inquiry as I was not convinced of their value for all sorts of historical research indiscriminately. Andrea and Raluca have been supportive, allowing me to make the project my own. I also want to thank Silvia Donker, my PhD colleague on the project: Silvia's feedback and our discussions about finding our place in the project and the broader academic maze have been very helpful.

The (PhD) community at the Groningen Faculty of Philosophy has been amazing to work with. It has been great to learn from so many extraordinary people. Whether during seminars, work-in-progress sessions, reading groups, or simply by the coffee machine, these daily interactions (during the non-pandemic period, whenever it was possible) all provided energy and ideas to continue this research. I list some people here, and I apologize to those I omit, thank you: César, Christian, Crystel, Emar, Ervin, Federico, Hendrik, Iris, Kim, Maaike, Martin, Matthias, Merel, Mike, Michael and Silke. Additionally, I would like to thank Harmen Grootenhuis, with whom I co-taught a course of our joint design on monism throughout history. I very much enjoyed working together teaching such a great course and hope we get to work together again sometime. I thank Merijn Weij for helping me with formatting the reference list and Robin Riemersma for going over drafts of multiple chapters.

Wim Mol has been a friend and collaborator ever since we met during our undergraduate studies in philosophy. I fondly remember our reading of *Wandering Significance: An Essay on Conceptual Behaviour*, by Mark Wilson, which turned out to be so important to my overall understanding of vector semantics. Additionally, thanks to my colleague Laura Georgescu for recommending me to pick up Wilson's massive tome at the start of my PhD-project.

This dissertation contains elements from an already published article, co-authored with Wim (Hogenbirk and Mol 2022). In 1.3.2 and 1.4 parts of the explanation of vector semantics are taken from this article. The main thrust of Chapter 3 follows that of the article. Additionally, parts of a team paper (Sangiacomo *et al*. 2022c) are found in section 1.6 in which parts of the co-developed method are detailed.

To my parents Dick and José, thank you for the eternal support I receive from you. To my brother Joris, thank you so much for all the energy you have spent keeping my head on straight. To my girlfriend, Laurisa, I love you and I think we are doing great!

Hugo Dirk Hogenbirk
07-11-2023, The Hague

Abstract

The development of early modern natural philosophy is often associated with the occurrence of the "Scientific Revolution" and, therefore, it is often seen as a precursor of science as we know it today (Henry 2008). Three distinct schools are usually identified as the main competitors in the history of early modern natural philosophy: scholastic, Cartesian and Newtonian (Lind 1992; Blair 2006). A simplified story might go as follows: Cartesians argue against and eventually replace the scholastics; later, Newtonians argue against and eventually replace Cartesians. Yet, recent scholarship has also pointed out that the borders between the schools are not as rigid as was once thought (Des Chene 1996; Ducheyne 2005; Schmaltz 2008) and that they co-existed for significant periods of time (Sangiacomo *et al.* 2022b). The degree to which they are similar or dissimilar and how they differentiate themselves from one another remains a problematic issue. One difficulty is that historians usually approach this development, which spans over two hundred years, via the close-reading of selected case studies, which entails that the larger picture can only be constructed through qualitative generalizations.

In this dissertation, I investigate conceptual development in natural philosophy and the different ways in which particular concepts are used by each of these different schools. More specifically, I explore the nature and the degree of conceptual unity that occurs between them, within them, and across specific terms. To do so, I incorporate techniques for computational text analysis (vector semantics) and methodologically build upon them in novel ways. By looking at the use of key terms in early modern natural philosophy and by computationally modelling their meanings, I am able to survey a corpus of 731 works of natural philosophy spanning across the seventeenth and eighteenth centuries. Scholastics, Cartesians and Newtonians prove not only to have different amounts of internal conceptual cohesion, but also to use different semantic strategies with regards to key terms, which result in differing sorts of conceptual innovation.

This dissertation, thus, aims at understanding the changes in the meanings of words and concepts across early modern natural philosophy and how, through these changes, different schools and authors were able to influence others, foster conceptual unity and develop different semantic strategies. To operationalize this aim, I will address four core questions, each of which will be the focus of individual chapters. First, are the main schools of natural philosophy conceptually and semantically unified internally? Second, what words play particularly important roles in the development of natural philosophical schools and in what ways? Third, can semantic similarity be used to trace potential routes of author-to-author influence and could this be disentangled from doctrinal similarity? Finally, assuming the answer to the previous question is positive,

what books in the seventeenth and eighteenth centuries were conceptually innovative and disruptive?

Chapter 1 first introduces the broad historical framework of the dissertation. I argue that the methods I propose fit best as a continuance of *begriffsgeschichte* (a historical approach that focuses on repeated uses of vocabulary) as opposed to a 'history of ideas' (Wevers and Koolen 2020). Despite my computational approach being *prima facie* opposed to Ariana Betti *et al.*'s model approach (2019), I argue that the two approaches can peacefully coexist as they differ in choosing their stable objects of investigation. Whereas Betti *et al.* investigate unit-ideas that retain a stable core throughout history, I investigate the repeated uses of terms, and the effects linguistic continuity has on further thought. Then, I outline the basic methodology behind my research, namely, the construction of a vector model of a word's meaning in a text. Using these models, a degree of semantic similarity among different works can be formulated. Finally, I discuss the origin and specifics of the corpus used throughout the dissertation.

In Chapter 2, I introduce a measure of conceptual stability of the corpus under scrutiny in order to see how semantically unified the three schools of natural philosophy are. For a key term such as 'cause', 'body', 'earth' or 'method', stability considers how similar the idiosyncratic meanings of words in all works in the corpus are. Building on stability, I posit that we can find more or less stable words for different corpora. Cartesians are the most unified in the concepts they attach to terms, while the scholastics are the least so.

In Chapter 3, I build on the stability measure introduced in Chapter 2 where I extend the analysis of individual terms. I do this by comparing two choices in the construction of semantic models; one which uses all the words close to another and one which uses merely the words that are most disproportionately present. Relying on the work of contemporary philosophers of language (Wilson 2006; Haslanger 2012), I argue that both capture an aspect of meaning. The latter captures the most salient way to understand a word, while the former captures the subtle ways in which words are used overall. Combining this insight with the stability scores of individual terms, I can interpret the discrepancies between stabilities extracted using the two different models of meaning. These are used to discover terms with atypical behavior within the corpus of natural philosophy. I argue that the term 'body' plays a pivotal role in unifying early modern discourse, whereas 'method', 'fire' and 'electricity' are surprisingly unstable in their inconspicuous usage, while being saliently stable.

In Chapter 4, I consider semantic influences and how they run between single authors. I link the influence of Cartesian mechanicism to Anne Conway's *Principles.* I argue that the semantic similarity of two authors (introduced in Chapter 1 and

aggregated as stability in Chapter 2) can be interpreted as an indicator of a relation of semantic influence that runs between those two authors. More specifically, I extract the semantic similarity between Conway's work and works by figures whom she has been traditionally associated with. This allows me to reassess Conway's placement as working within the vocabulary of mechanicism despite her direct opposition to René Descartes' philosophy.

Finally, in Chapter 5, I broaden the scope of the influence analysis of Chapter 4. I investigate the whole Latin corpus for both very influential works and works that break with their past. I interpret titles that do both as works that are successful innovators within the corpus. On these grounds, I move beyond the simple description of unity and disunity outlined in Chapter 2. Instead, I argue that we find Newtonians to remain faithful to their own particular strategy of semantic innovation; Newtonian trailblazers are ostensibly mere "popularizers" of Newtonian thought but, in reality, are conceptual innovators. Additionally, terms that are the target of semantic innovation are terms usually associated with the new philosophy, whereas scholastic terms come out as hardly innovated upon.

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0: Introduction

"Seeing the truth drains magic power."

(Shigeru Miyamoto, *The Legend of Zelda: Majora's Mask* 2000)

0.1: Quantifying the Schools of Natural Philosophy

The development of early modern natural philosophy is often associated with the occurrence of the "Scientific Revolution" and, therefore, it is often seen as a precursor of science as we know it today (Henry 2008). Three distinct schools are usually identified as the main competitors in the history of early modern natural philosophy: scholastic, Cartesian and Newtonian (Blair 2006). A simplified story could be envisaged like this: Cartesians argue against and eventually replace scholastics. Later, Newtonians argue against and eventually replace Cartesians. Yet, recent scholarship has also pointed out that the borders between the schools are not as rigid as it was once thought (Des Chene 1996; Ducheyne 2005; Schmaltz 2008) and that they co-existed for significant periods of time (Sangiacomo *et al.* 2022b). The degree to which they are similar or dissimilar and how they differentiate themselves from one another remains a problematic issue. One difficulty is that historians usually approach the development of early modern schools, which spans over two hundred years, via the close-reading of selected case studies, which entails that the larger picture can only be constructed through qualitative generalizations. I propose to enrich these discussions with quantitative considerations via computational tools applied to a sizable history of philosophy corpus, which could help us better understand the conceptual development of early modern natural philosophy and knowledge making.

Quantitative investigations of knowledge development resemble 'scientometrics', the study of quantitative features of science and scientific research. However, the most readily available resource for doing scientometrics are citations. Citations allow for the reconstruction of routes of social and conceptual influence and thought as they pass through scientific activities (Leydesdorff 1998). Additionally, by looking at who cites whom, we can discover structural features of (the development of) scientific disciplines. The historical setting of this dissertation, however, does not allow for the use of many of the methods that are used in scientometrics, in particular those

that are citation-based.[1] Early modern authors cite sparingly, cryptically and in a non-standard manner. To quantitatively investigate these historical materials, I need a different approach. Thus, I incorporate techniques for computational text analysis (vector semantics) and build upon them a new methodology suitable for studying an early modern corpus. By looking at the use of key terms in early modern natural philosophy and by computationally modelling their meanings, I am able to survey a corpus of 731 works of natural philosophy spanning across the seventeenth and eighteenth centuries. Using these methods, I trace the different ways in which particular concepts are used by each of the three main schools of natural philosophy. Scholastics, Cartesians and Newtonians prove not only to have had different amounts of internal conceptual cohesion, but also to have used different semantic strategies with regards to key terms, which resulted in differing modes of conceptual innovation.

This dissertation thus focusses on understanding the changes in the meanings of words and concepts across early modern natural philosophy and on how, through these changes, different schools and authors were able to influence others, foster unity and develop different semantic strategies. To operationalize these objectives, I will address four core questions, each of which will be the focus of individual chapters. First, are the main schools of natural philosophy conceptually and semantically unified internally? Second, what words play particularly important roles in the development of natural philosophical schools and in what ways? Third, can semantic similarity be used to trace potential routes of author-to-author influence and could this be disentangled from doctrinal similarity? And, finally, assuming the answer to the previous question is positive, what books in the seventeenth and eighteenth centuries were conceptually innovative and conceptually disruptive?

An important step in addressing these questions relies on different ways to computationally exploit the idea of 'conceptual similarity' of pairs of philosophical works. The core idea derives from Thomas Kuhn's (1922 – 1996) theory of scientific revolutions (Kuhn 1962), and from his suggestion that disciplines are formed around 'paradigms'. These paradigms not only incorporate doctrinal agreements among practitioners about how the world is, but also broader conceptual frames that allow the practitioners to mean the same things when they speak and write. Practitioners who share such a conceptual frame make sense of the world in similar ways, although they can easily disagree on specific issues. Implicit conceptual agreement, then, allows for easier communication and for easier 'building' upon each other's ideas and outcomes. When science (or a philosophical school) operates in such a way, it is called 'normal

[1] Which is not to say that the analysis of more modern philosophy cannot be approached using bibliometrics. See, for example, the work by Eugenio Petrovich (2018 and 2022).

science'. At the opposite end, when paradigms shift or multiple paradigms exist and are in dialogue with each other, the discipline is in a state of 'revolution'.

The aim of the computational methods is to approach the 'idiosyncratic meaning' of terms in specific works of philosophy and to then quantify their similarity to other works' idiosyncratic meanings (of that same word). I hypothesize that semantic similarity signals conceptual agreement and, conversely, that semantic dissimilarity signals conceptual disagreement. A group of works that are all conceptually and semantically similar will be stable and exhibit features of normal science. By contrast, a group of works (on the same topic) that are conceptually dissimilar, suggests that multiple schools exist within the corpus that are at odds with each other and that the corpus exhibits some features of revolutionary science.

I use a method called vector semantics in order to model the 'idiosyncratic meaning' of terms or keywords, which is specific to individual works of natural philosophy. Vector semantics is based on linguistic theories that suggest the importance of usage and contexts of utterance for the conceptual content of terms. The rationale is often summarized through the linguist John Firth's (1890 – 1960) creed: "You shall know a word by the company it keeps." (Firth 1957) Meanwhile, if we accept that conceptual content is communicated through the (aggregated) use of a term, then we can also make sense of modeling the meaning of sets of linguistic practices of different sizes. We are not restricted to model the meaning of a term for a whole language; instead, we can ask for works from different periods or produced by different groups (Jarlbrink and Noren 2019; Wevers and Koolen 2020) and even, as I shall discuss in what follows, for different individual works, how their particular use of a term is (dis)similar to that of other works. Firth offers here another creed that resonates: "Each man his own Babel!" (Firth 1937/1967, p.23). However social, speech is in the end a unique expression of our own being.

Yet, as I won't be looking at individual people, but individual books, Firth's creed is amended for this dissertation to *Each book its own Babel*. Although most of the investigations will be about the development of schools in early modern natural philosophy, one of the core assumptions of the dissertation is that every single book in the corpus is both a product of a causal semantic chain (including other books in the corpus) and is itself the initiator of a new one (however short it might be). Whereas citation-based analysis would focus on purely relational properties, my methods start off by modeling the *Babel* of each particular work individually. It is only from there onwards that relational properties can be extracted in order to reconstruct the ways in which the different actors in the period did or did not organize themselves into schools.

Several questions seem to be in order: how does one extract the idiosyncratic meaning attached to words from singular books? Where do these methods come from? And where do they find application? Analyzing large amounts of texts for the extraction of information or structural features already implies that the dissertation operates within the field of Digital Humanities–an umbrella term for humanists working with digital methods and materials. These methods have in recent years been applied to many fields of the humanities such as (cultural) history (Cohen *et al.* 2008; de Bolla 2013; Graham *et al.* 2016; Felice 2016; van Eijnatten 2019; van Eijnatten and Huijnen 2021), media studies (Sayers 2018; Bilgin *et al.* 2018) and literary-studies (Jockers 2013; Bode 2018; Underwood 2019; Eve 2022). By contrast, the field of history of philosophy has, as of yet, not made extensive use of these methods. Digital Humanities adapt traditional methods for the investigation of humanistic materials to digital means, sometimes qualitatively, sometimes quantitatively and sometimes by combining the two approaches. It is in these materials that I find many of the fundamental methods that I will be applying.

However, although I aim at a bird's eye view of the development of concepts and schools in the seventeenth and eighteenth centuries, I will still be dealing with materials that have been considered mostly within the history of early modern philosophy. This is a field that normally proceeds by close reading, analysis and comment of (certain) texts. A quick glance at the contents of a random issue of the *British Journal for the History of Philosophy* (for example volume 29, no. 3, 2021) provides a case in point: of the nine articles, seven are (as can be inferred from their titles alone) clearly explications of concepts or doctrines within the work of either individual philosophers (e.g., "Madness and vice in Plato's *Republic*" or "Why did Frege reject the theory of types?") or in correspondences between two philosophers (e.g., "The indefinite in the Descartes-More correspondence"). To do history of philosophy, quite often, means understanding and explicating a previous thinker's works in an as engaged and specific way as possible. As a general rule, philosophical texts are difficult to parse so their explication is both intellectually valuable and challenging. That is not to say that there is not a more contextually informed way of doing history of philosophy (Mercer 2019) that involves and informs the conceptual analyses historians execute. However, even context-sensitive analysis is centrally concerned with the close reading of thinkers throughout history.

This dissertation aims at combining history of philosophy and digital humanities methodology. But from the short sketch above, it seems apparent that the two approaches are not necessarily consistent in aims and methods. In fact, despite focusing on a corpus related to the history of early modern philosophy and science, the dissertation makes relatively little use of the sort of close reading common in more

traditional history of philosophy scholarship. In order to show how I attempted to create a virtuous synergy between traditional approaches in the history of philosophy and digitally-inflected humanities methods, I shall explain some of the issues I deal with that can be placed within a 'history of philosophy' approach.

0.2: Situating the Dissertation in the History of Philosophy

Computational methods are far from common in the history of philosophy. However, there have been a number of projects in recent years that deal with historical philosophical texts using computational aides. First, a team led by Ariana Betti in Amsterdam (Ginammi *et al.* 2022) has been working on the analysis of corpora for studying conceptual shift by using what they call a 'model approach' to concepts (Betti and van den Berg 2014; Betti *et al.* 2019). The model approach entails explicitly formulating an abstract model of a concept that a researcher wants to trace over time. The model distinguishes between core and marginal features; while the first are essential for recognizing the same concept, the latter can change over time. Keywords are derived from both core and marginal features of the model, and they allow for searching texts. Usually relying on a mixture of automated processes and human annotations, keyword search is used to identify occurrences of variations of the same idea (as it has been modelled) across different texts. Eventually, by taking into account the difference between core and margin, reading all these occurrences of a concept, and annotating how the concept is used specifically, the researcher can draw conclusions about the concept's shifts over time. Vector models of meaning, instead, are only used insofar as they can be coupled with ground-truth annotations (Betti *et al.* 2020, Bloem *et al.* 2020).

Several researchers used network reconstructions to explore philosophical corpora. For instance, Andrea Sangiacomo and Daan Beers used network analysis for studying the state of the Republic of Letters represented as epistolary networks. (Sangiacomo and Beers 2020). Eugenio Petrovich investigated the history of analytic philosophy via bibliometrics, meta-data analysis and word counts of vetted corpora of analytical philosophical articles (Petrovich 2018; 2022; Buonomo and Petrovich 2018). Matteo Valleriani ran a project that created a multilayer network of *De Sphaera* editions making use of both semantic modeling of small bits of text (Zamani *et al.* 2020) and bibliographic metadata (Valleriani *et al.* 2022). Mark Alfano studied Nietzsche using the occurrence counts of key terms and the cooccurrences of these key term to one another, as they occur throughout the Nietzschean corpus. (Alfano 2019).

Nevertheless, these studies do not focus on the conceptual development of schools of philosophy as is done in this dissertation, nor do they employ the broad family

of methods used in this dissertation, that is, bottom-up vector semantic models of meaning. The implementations of the latter approach have been far and few between in philosophy. The present research constitutes the first systematic application of these methods on historical philosophical corpora for the purpose of analyzing the formation and development of philosophical schools.

Although novel in the applications of vector semantic models of meaning, my dissertation asks questions that are currently at the periphery of historical philosophical research rather than at its center. In doing so, I surmise that these questions should, in fact, receive more attention in historical research, and that the methods I shall illustrate facilitate their investigation. Firstly, I focus on the development of the conceptual profile of certain terms via their linguistic occurrences. This might broadly be included in the category of conceptual history by computational means (Wevers and Koolen 2020). The computational means are methods that derive meanings of terms by studying the word's contexts of occurrence. The use of these methods implies that I have bought into a particular theory of meaning, according to which the meaning of words derives not only from the definitions one may give of those words, but also from their general use and application. Such a 'distributional theory of meaning' (Landauer and Dumais 1997; McDonald and Ramscar 2001) implies that not all meaning making is conscious; much is implicit and distributed across different facets and contexts of a word's use. This also relates to my broad view of the development of concepts. As I shall illustrate, concepts (sometimes abbreviated by words) often change not because of our conscious interest in conceptual development, but rather their meaning shifts casually due to the changing demands put on our intellectual powers by the context in which we operate. Such conceptual changes over time are usually called 'conceptual drift'. As Mark Wilson puts it in *Wandering Significance,* his excellent exploration of the workings of concepts:

> Intuitively, we expect that the developments of genuine recipes of practical advantage represent important *anchoring points* in the developmental history of a language: once a linguistic routine has become firmly planted in the sands of practicality, our other forms of linguistic endeavor must respect its work capacities. We will not want to abandon [linguistic] tools that accomplish worthy ends unless we have found superior replacements that can reach allied objectives. (Wilson 2006, p.228)

These processes of anchoring around, for example, semantic recipes, are beneficial for us humans, as they allow us to understand what needs to be understood (and done) more easily. However, it also leads to partial opaqueness in the conceptual drift, as the shifts made are quite often subterranean (Wilson 2006, p.229). Even when the existence of a shift is clear to the contemporary observer, the nature of the shift can still remain

opaque. As such, the computational analysis of large corpora might be a fruitful way to investigate issues of conceptual drift, since the methods used (especially vector semantics) are generally sensitive to textual structures that do not immediately reveal themselves to the human reader (Gavin *et al.* 2019) or even to an author we might have asked about their own text. Conceptual history is considered more extensively in Chapters 2, 3 and 5. The stability of concepts is considered in Chapters 2 and 3. The investigation of what words are hotbeds of *innovation* within a corpus is approached in Chapter 5. In Chapter 5, I will also argue that mathematical and typically Newtonian terms are innovated upon highly.

The dissertation also broaches questions of intellectual history and influence. Influence is an ambiguous term. People might influence other people in many particular ways. Additionally, whereas in modern sciences authors aim to be explicit about who they draw on (which can be leveraged in order to quantify influence) this is not the case in early modern philosophy (Palacios-Huerta and Volij 2004), making extracting influences even more puzzling (van Bunge *et al.* 2011). However, I am not dealing with influence in all its forms. Here, the term 'influence' is meant to be restricted to *semantic influence*–texts or people that influence the use of language, concepts and meanings of another person. Semantic influence might coincide with doctrinal influence, but in Chapter 4 I will argue it generally does not. Semantic influence is most extensively exerted in early childhood (when we learn to speak any one particular language). Although a more thorough investigation of language acquisition could further inform methods for interpreting and generating semantic algorithms, this is left aside here as an avenue for further research. I shall thus restrict my investigation of 'semantic influence' from the broad language acquisition (and meaning acquisition) that happens in early childhood to 'semantic influence' as more commonly discussed in the history of philosophy and science. The focus will be in particular on the development and influence that occurs with regard to the use and meaning of key *technical* terms that are central to natural philosophy. These influences might be expected to take place later in life, for example during higher education or even further on in the development of a thinker's semantic profile. These issues are considered in Chapters 4 and 5. In Chapter 4, I provide a case study to investigate whether we might be able to discover which authors or traditions have influenced the thought of Anne Conway (1631 – 1679) via a combination of historical vetting of possible sources and computational scoring. The closest correlate in the philosophical literature are studies that investigate Platonic style in order to attribute certain works to Plato and others to other authors (Ledger 1989; Temple 1996). In Chapter 5, I also look at potential ways to extract particularly *innovative and influential works* from corpora (by using the previously developed idea of influence),

with potential applications not only for history but also for canon expansion. It turns out that the canon already overlaps significantly with innovativity within the corpus.

0.3: Semantic Unity and Doctrinal Discord

The single and unified upshot of the dissertation is that semantic influence and conceptual development run parallel to broad tendencies that have been identified in the literature (Blair 2006; Sangiacomo *et al.* 2022b). Newtonian, Cartesian and scholastic authors are traceable schools that show themselves via their semantic profiles, as we will see in Chapter 2. Authors belonging to these schools are not only unified by their particular doctrinal agreements, but also by their use of language which is tuned into that of one another. All the actors within a single school share a specific and distinctive use of terminology. Quite interestingly, the profiles of these groups of works are not 'timeless universals' that unify their use of terms. In Chapter 5, we will see that, over time, different terms are the most important topics of innovation for different schools. There is an agreement not only about the use and meaning of certain terminology among members of a school; there even appears to be, especially among the Newtonians, an agreement about where the conceptual frame is still open to further development. Newtonians agree both in the broad outline of their program of research and on where work remains to be done, including where there is room for conceptual alterations to their broad structure.

The diffusion of these broad semantic contexts seems to be reducible neither to personal circumstance nor to doctrinal differences only. Semantic influence does not run counter to disagreeing extensively with the source of influence. For instance, as I argue in Chapter 4, I find Thomas Hobbes (1588 – 1679) and René Descartes (1596 – 1650) as the most likely sources for Anne Conway's *Principles* by computational considerations, in spite of her explicit doctrinal disagreements with exactly these two authors. However, her explicit disagreement plays itself out within a similar broad outlook on the meaning of the terms used: Conway just tends to disagree with them *about* bodies, movement and so on, while agreeing in how to make sense of these concepts. Personal influence (such as from her mentor Henry More 1614 – 1687) also does not necessarily translate into semantic influence (perhaps not fully unexpected as More started out influencing Conway by teaching her Cartesian philosophy).

Then, if not directly correlated with doctrinal disagreement, what is the origin for the diffusion of these broader frames of meaning? How do certain groups of people start talking in the same way about the technicalities of their craft? Partly, it must be a question of education or formative years: to speak in a particular way is a product of how others around you speak and how you are taught to speak and write (from

childhood to higher education). To allow the education of others, linguistic agreement or sedimentation and an institutional framework are necessary. But a school's 'way of speaking' needs to originate somewhere and, after originating, needs to be improved and refined. I take the results about innovativity found in Chapter 5 to be an indicator of figures who played such roles of originators and refiners. Although we might feel reassured to find canonical figures and heads of respective schools among the higher scoring authors, some of the most important innovators turn out to be what are commonly referred to as *popularizers* or *appropriators*, like Pieter van Musschenbroek (1692 – 1761) and Willem 's Gravesande (1688 – 1742). This corroborates (through computational means) Steffen DuCheyne's recent insistence on van Musschenbroek's and 's Gravesande's indebtedness to Isaac Newton (1642 – 1726), which they then combined with conceptually innovating using his thought (DuCheyne 2014a; 2014b; 2015; DuCheyne and Present 2017). The broader semantic frames come into being and get consolidated not only by the posited 'geniuses', but also by those who make the genius' work conceptually available: making the work 'more easily digestible' is, in fact, the same as developing the broad semantic package.

The shadow-play of the doctrinal and personal connections in terms of semantics is found also in the stability of key terms within the whole corpus. When we zoom out and merely look at the stability of certain terms within natural philosophy, we find recognizable results. Instability might indicate development (if properly segmented into particular schools with their own semantic profiles), but might also indicate chaos. In the latter case, instability signals that practitioners are using different conceptual vocabularies. Originally scholastic metaphysical terminology that is later taken up by other thinkers is found to be among the most unstable terminology, suggesting that, during the development of natural philosophy, the gap between the meaning of these words attached by the different schools widened. And they did so across exactly those philosophically central terms (like 'cause' or 'matter') that might have been thought to secure at least some form of continuity between them. Finally, a particularly typical semantic role is found to be played by the term 'body'–where open and salient differences are belied by subtle *agreements* in the usage of the term. As such, I conclude, 'body' plays a pivotal, unifying role for many different positions taken in natural philosophy; to propose a new system of philosophy is to propose a new theory of body, but underneath such an endeavor lies some explicit semantic unity in usage that helps tie the different views together and ensures that they are indeed talking about the same in some sense despite their apparent irreconcilability.

0.4: Overview of the Chapters and Dissertation

Chapter 1 first introduces the broad historical framework of the dissertation. I argue that the methods I propose fit best as a continuance of *begriffsgeschichte* (a historical approach that focuses on repeated uses of vocabulary) as opposed to a 'history of ideas' (Wevers and Koolen 2020). Despite my computational approach being *prima facie* opposed to Ariana Betti *et al.*'s model approach (2019), I argue that the two approaches can peacefully coexist as they differ in choosing their stable objects of investigation. Whereas Betti *et al.* investigate unit-ideas that retain a stable core throughout history, I investigate the repeated uses of terms, and the effects linguistic continuity has on further thought. Then, I outline the basic methodology behind my research, namely, the construction of a vector model of a word's meaning in a text. Using these models, a degree of semantic similarity among different works can be formulated. Then, I discuss the origin and specifics of the corpus used throughout the dissertation. The discussion of these methods is both explanatory and justificatory, as these methods have already been used in many contexts (Gavin *et al.* 2019; de Bolla *et al.* 2019; Wevers and Koolen 2020). Afterward, I introduce the specifics and origin of the multilingual corpus used throughout the dissertation, which has been compiled within the context of the European Research Council (ERC)-funded project "The normalisation of natural philosophy; How teaching practices shaped the evolution of early modern science." The corpus provides the basis for studying the underlying development of concepts and schools during the period. Moreover, it consists of elements (i.e., specific influential books) that have themselves been causally active in the development of concepts and schools. The corpus is split into three monolingual subcorpora, as the methods used do not work cross-lingually. Finally, in order to generate a cohesive overview of the corpus I model the corpora as networks. I explain how multilayer networks can be constructed by applying vector semantic methods to a corpus of digitized texts. Here, I introduce multilayer key-word-based networks as they have been developed in the context of the ERC-project. (Sangiacomo *et al.* 2022c; Sangiacomo and Tanasescu 2022).

In Chapter 2, I present the three mono-lingual subcorpora (Latin, English and French) as keyword-based networks. The three networks will be presented and analyzed for their more general properties. To this end, I introduce a measure of a corpus' conceptual *stability*. By considering the similarity of every works' idiosyncratic meaning to every other work (for a particular word), I argue that we can find more or less stable words for different corpora. The stability measure is then used first to investigate the stability of different key terms. I ask: "Do the purported schools of seventeenth- and eighteenth-century natural philosophy exhibit strong conceptual unity?" I answer affirmatively by using statistical testing of average stability, together with annotations

of the works' affiliation. There is a clear increase in stability when checking same-school connections and a clear drop when checking cross-school connections. Additionally, Cartesians are most stable and the scholastics the least so.

In Chapter 3, I compare two ways of constructing semantic models: a first one which uses all the words close to another given word, and a second one, which uses merely the words that are most disproportionately present. Relying on the work of contemporary philosophers of language (Wilson 2006; Haslanger 2012), I argue that both approaches capture an aspect of meaning. The latter captures the most salient way to understand a word, and the former captures the subtle ways in which words are used overall. I analyze the stability scores of terms using these different models of meaning. The discrepancy between the scores is used to discover terms with atypical behavior within the corpus of natural philosophy. I argue that the term 'body' plays a pivotal role in unifying early modern discourse, whereas 'method', 'fire' and 'electricity' are unexpectedly unstable in their inconspicuous usage, while being saliently stable.

In Chapter 4, I argue that the semantic similarity of authors can be interpreted as an indicator of a relation of semantic influence that runs between said authors. I implement this general idea by tracing the influence of Cartesian mechanicism to Anne Conway's *Principles.* More specifically, I extract the semantic similarity between her work and works by figures whom she has been traditionally associated with. Relying on tracing semantic influence, I reassess Conway's placement as operating within the vocabulary of mechanicism despite her direct opposition to Descartes' philosophy. The re-evaluation of Conway's historical placement is carried out by looking at Henry More; Francis van Helmont (1614 – 1698); George Keith (1638 – 1716); Christian von Rosenroth (1636 – 1689); Thomas Hobbes; René Descartes; Baruch Spinoza (1632 – 1677); Jan Baptist van Helmont (1580 – 1644); Margaret Cavendish (1623 – 1673); and a tract by an anonymous author published in the same volume with Conway's work. The results suggest that Conway is semantically similar to Hobbes and Descartes, which points at her deserving a place within the broad tradition of mechanistic metaphysics and shows the impact of Descartes' conceptual innovations. Keith, More, J.B. van Helmont, and von Rosenroth score very low, suggesting there is no relation of semantic influence between them and Conway.

Finally, in Chapter 5, I build on the previous interpretations and techniques to define a measure for the innovativity of a specific text relative to a corpus of texts. By considering works that have few potential influencers (low semantic continuity with the work's past) and that have many works that it has potentially influenced (high semantic continuity with the future), we can extract works that are successful innovators within the corpus. My approach mimics those in scientometrics that aim to identify disruptive

or innovative papers using citations (Funk and Owen-Smith 2017; Park *et al.* 2023), but using semantic tools (rather than citations), which are available for my historical data. On these grounds, I move beyond the simple description of unity and disunity as was done in Chapter 2. Innovativity allows us to see what words (certain authors) are being particularly innovative about, and who these innovative authors are. However, I also draw attention to the overlap between the innovation scores of the entire corpus and our own preconceived notions about the 'canonicity' of the authors in the corpus. I argue that we find Newtonians to remain faithful to their own particular strategy of semantic innovation; Newtonian trailblazers are ostensibly mere "popularizers" of Newtonian thought, but, in reality, they are conceptual innovators. Additionally, terms that are the target of semantic innovation are terms usually associated with the new philosophy, whereas scholastic terms come out as hardly innovated upon. I found that there is significant statistical overlap between the canonicity score and the innovation score in the corpus, suggesting that innovativity is a causal factor in the construction of the canon.

Methodologically, the dissertation consists of three major parts. The first part consists of Chapter 1, which informs all the other applications in the rest of the dissertation. Chapter 2 and 3 consider the issue of semantic stability of both schools and terms. Chapter 3 builds on Chapter 2 and makes the analysis of stability more fine-grained. Finally, Chapter 4 and 5 consider semantic influence. Chapter 4 approaches this topic first in the form of a case study. Chapter 5 builds on Chapter 4 by both extending the scope (considering the whole corpus) and developing the notion of semantic influence further into one of semantic innovativity. Figure 0.1 gives a schematic overview of the structure of the chapters.

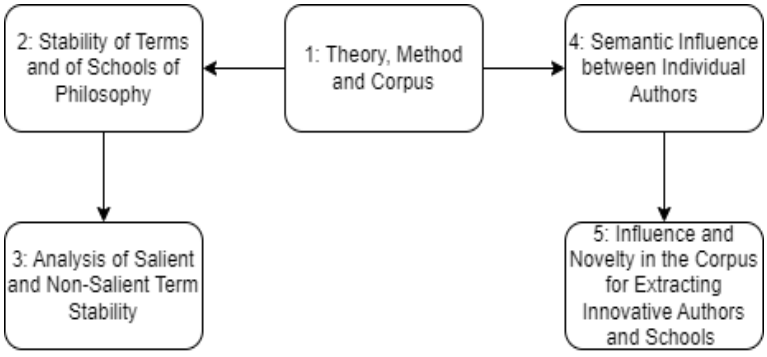

Figure 0.1: Overview dependence structure of chapters in the dissertation

1: Computational History of Concepts, Method and Corpus

> "We live in age of 'phones' – gramophones, telephones, microphones, and goodness know how many other 'phones'. Excellent though all these things are, we must not become obsessed with the technique of reproducing disembodied voices that we regard speech as being mainly an affair of frequencies, amplitudes, decibels, and standard vowel resonances. Speech is the outcome of flesh and blood, a bond between kith and kin. It is influenced by all that flesh is heir to, by what is bred in the bone, and it is also part of those manners, which 'mayketh man'."
>
> (John Rupert Firth, *The Tongues of Men* 1937/1964, p.89)

1.1: Introduction

We live in an age that bears the marks of digital space, computers and, by way of consequence, the computer's instructions (i.e., algorithms). This dissertation develops and applies such digital affordances in order to represent the social and semantic dimensions of historical books and words. Yet, the way the books (whose contents figure as the input for our methods) were able to exercise any historical influence or manifest ongoing conceptual developments was due to these works being written and read by humans. It is only through people that language can exist and do its fateful job. The dissertation however, begins at first with the assumption that language can be investigated without making the relation to the human mind and human practice explicit. Nonetheless, as the discussion unfolds, humans are reintroduced to make it possible to connect the results of the algorithms back to the historical reality.

The first section of this chapter details the broader framework of conceptual history within which the dissertation operates. I consider both *begriffsgeschichte* (deriving from the works of Reinhart Koselleck) and the history of ideas (deriving from the works of Arthur Lovejoy). Both have seen recent computational applications: *Begriffsgeschichte* by Melvin Wevers and Marijn Koolen (2020) and history of ideas by Ariana Betti and her research team (Betti *et al.* 2019). I position myself within the discipline of digital *begriffsgeschichte*, meaning that I will use a word-first (and not idea-first) approach to the investigation of the history of concepts.

The second section introduces the linguistic intuitions and state of the art of extracting vector models of meaning from texts. I describe the differences between the most recent methods for semantic modelling based on word embeddings and the type of vector semantics that I will adopt instead. Additionally, I consider some general problems, already pointed out by James Dobson (2021), for interpreting individual vectors in a vectorial approach to texts and meanings. To alleviate these interpretative issues, I provide an extensive introduction to the methods used in the section thereafter.

Thus, in the third section, I explain the rationale and implementation of the methods that attempt to extract models of word meaning by considering the contexts of these words in the texts. This family of methods, called 'vector semantics', is closely related to collocate extraction, a method that retrieves words strongly connected to a word of interest. These models are applied in order to operationalize the idea of semantic similarities of texts.

In section four, I introduce the corpus that will be studied throughout the dissertation. The full rationale and the composition of the whole corpus have been accounted for in several collective contributions (Sangiacomo *et al.* 2021a; 2021b; 2022b). The corpus is made up of early modern works on natural philosophy, often textbooks or textbook-like. The way the corpus was selected directly bears on the interpretation of the results and should be considered in any and all conclusions drawn. Particular attention will be given to the method of the digitization of the corpus, called Optical Character Recognition (OCR), and to its implications for the results.

In the fifth and final section, I combine the methods discussed in section three and the corpus introduced in section four, to formulate a proposal (developed partly in Sangiacomo *et al.* 2022c) to use vector methodology to link together different books in their specific usage of different words. Tying together all the works in the corpus results in a network representation based on their pairwise similarities. The resulting network is the basic object of study for a number of investigations of the corpus in later chapters, and provides a visible and tangible outcome of the interrelatedness of the works in question.

1.2: Two Approaches to (Computational) Conceptual History

My general purpose in this dissertation is to investigate the stability of schools of natural philosophy, routes of influence that run between authors, innovativity and terminological impact. The methods detailed in this chapter have as their goal to extract the meaning and the differences in meaning from philosophical texts. However, before

I move on to these topics, I first need to place the basic approach–semantic modelling–within the history of philosophy.

The dissertation does not focus on individual authors in particular, but on groups of works, for the sake of studying large scale semantic and conceptual changes across these groups of works. Moreover, the dissertation does not consider the philosophical arguments of the works under scrutiny, but terms and their shifting meanings. Rather, the broad frame of the dissertation is one concerned with the development of ideas, words and concepts, and with how these either reflect on or cause developments at the level of school stability, influence and innovation. That is to say, the dissertation is an exercise in conceptual history. It is not, as Richard Rorty (1931 – 2007) would have called it, a dissertation aimed at "rational reconstruction", since arguments are not central to my analysis (Rorty 1984), whereas rational reconstruction aims at retrieving arguments and positions for our own use. Nor does the approach broadly agree with Quentin Skinner's dictum that "No agent can eventually be said to have meant or done something which he could never be brought to accept as a correct description of what he had meant or done." (Skinner 1969, p.28) The focus is not on actors, but, in the end, on the role that language and concepts play in the activities of thinkers and their broader contexts. Using terms in particular ways may have (had) an impact that goes beyond the intended impact of the actor employing them.

Instead, the most well-known subdiscipline that takes up conceptual history in the Anglo-Saxon world is the history of ideas. As Arthur Lovejoy (1873 – 1962), the originator of the discipline in the English-speaking world, puts it: "There are […] many "unit-ideas"[…] which have long life-histories of their own, are to be found at work in the most various regions of the history of human thinking and feeling, and upon which the intellectual and affective reactions of men […] have been highly diverse" (Lovejoy 1948/2019). The history of ideas considers 'unit-ideas,' ideas that can be taken up in different ways and that can play different roles in people's thinking, but which retain a stable sense of importance throughout history.

A different approach to conceptual history is *begriffgeschichte* (Richter 1987). *Begriffsgeschichte* is similarly focused on the different forms a concept might take over the course of history. Frederick Beiser (2016) recently suggested that the two approaches are very much akin, calling *begriffsgeschichte* a specification of the history of ideas, not focused on people, but on concepts themselves. There are, however, important differences between the two. As Reinhart Koselleck (1923 – 2006), one of the founders of *begriffsgeschichte,* characterized the difference:

> With more or fewer, greater or smaller deviations from earlier meanings, concepts may continue to be used or reused. Although such variations may be

> either marginal or profound, linguistic recycling insures at least a minimum degree of continuity. To the extent that it records how component parts of older concepts continue to be reapplied, Begriffsgeschichte resembles the history of ideas. […However,] any assertion about continuities in the use of concepts must be supported by evidence based upon *concrete, iterative usages of the vocabulary*. (Koselleck 1996, p.63, emphasis mine)

Although in many ways similar, the 'unit-ideas' of Lovejoy are more explicitly contextualized and psychologically situated in Kosellecks's approach. Although concepts are not reduced to words, it is accepted that the only way that concepts can function is through 'iterative usages of the vocabulary'. And the reason we might expect iterative use to be productive (whether with the same or different attached meanings) is because there is no way to insulate oneself fully from the previous meanings attached to the same word. Using the same word with a different meaning is itself a substantial move, modernizing, or bringing within one's own context, a term with already an established conceptual history. As Koselleck continues:

> [A] rigorous historicism views all concepts as speech acts within a context that cannot be replicated. […] Thus, although concepts age, they have no autonomous history of their own. […] But Begriffsgeschichte does not end there. Every reading by later generations of past conceptualizations alters the spectrum of possible transmitted meanings. The original contexts of concepts change; so, too, do the original or subsequent meanings carried by concepts. […] Therefore, the historical uniqueness of speech acts, which might appear to make any history of concepts impossible, in fact creates the necessity to recycle past conceptualizations. (Koselleck 1963, p.62)

Additionally, the concept becomes in this way (at least initially) discoverable via lexical stability, because the lexical stability will itself be an important causal factor in the development of thought. For instance, to write a history of 'causa' is not only an issue of finding out what 'causa' means and then seeing multiple authors wrestle with this concept or idea – it is also to trace the different applications of the lexical unit 'causa' to see how its use and meaning have changed. In order to have an initial "object of investigation," the 'word' is prioritized in order to see how the linguistic principles which underlie and facilitate changes in the use of concepts, function.

For the historian of ideas, the stable unit of investigation is not a word, but the unit-idea. The unit-idea might occur in different contexts, get 'dressed-up' differently and might be indicated by the use of certain words, but, in the end, it is not tied into any particular lexical unit. The advantage of the history of ideas approach is that it enforces a conceptual unity that is traced through time in the many ways it shows itself. There is

a stable and clear object that is traced by authors like Lovejoy in *The Great Chain of Being* (1936) and Michael Della Rocca in the *Parmenidean Ascent* (2021). To read Plato or Parmenides, for instance, is an exercise in excavating the core ideas that play a role in their thought and subsequent thought and then see how they deal differently with, respectively, *the principle of plenitude* and with *the principle of sufficient reason*. There is not a single (set of) keywords that could pick out these principles exactly. They are hidden within a wider web of language and argumentative structure. The 'iterative usage of the vocabulary' is of no particular interest, it is the iterative use of ideas that should be traced.

Both of the above approaches to conceptual history have in recent years been transposed into a computational method. In their paper "Digital Begriffsgeschichte", Wevers and Koolen (2020) show how to extract a measure of change that a term undergoes over time. By looking at the same lexical unit in a corpus over time, they extract the tempo of change the word undergoes. As they rightfully point out, the tradition of *begriffsgeschichte* can be brought in line with the computational semantic modelling of specific words.

The history of ideas has also been approached by Ariana Betti's team, who combine computational historical analysis of philosophical corpora with an attempt to model unit-ideas in order to trace their different associations (Betti and van den Berg 2014; Betti *et al.* 2019). This 'model approach' differentiates between what is unnegotiably central to an idea and what is not essential to it. Some changes to an idea would shift its core and then we would no longer be tracing the same idea, whereas changes to the periphery of the idea leave its core intact and can represent how the same idea changes over time. By explicating our intuitions and modeling them before we turn to the texts, Betti *et al.* (2014; 2019) argue that we become aware of our subject of investigation where otherwise we would have worked with an implicit model of the idea that we are tracing which would impact results in unknown ways.

Wevers' and Koolen's approach can be qualified as a 'bottom-up' approach to concepts (discovering concepts through linguistic activities), whereas Betti's might count as 'top-down' (modeling concepts *a-priori* and scouring texts in order to find the relevant key-words that they get associated with). Betti's approach has been used mostly for the analysis of corpora made up of the works by a single philosopher in order to quantify their adherence to one or another conception of a specific idea. By contrast, Wevers' and Koolen's approach lends itself for the consideration of large amounts of different texts. Since this dissertation will consider schools of natural philosophy over a period of 200 years for a multitude of different terms or concepts, the word-first approach better connects with the intended research. Additionally, *begriffsgeschichte*

allows me to discover more or less semantic unity between larger groups of texts in their attached meanings, providing the rationale for continuous differences between multiple texts in a way that the discrete model approach, with its top-down approach to similarities, does not.

The model approach provides us with clarity about the idea that is traced, whereas starting from lexical units lacks this advantage. However, this might not be a major issue for the sort of research that I develop here. By tracing the iterative usages of lexicon, I not only aim to trace the idea itself; I aim to trace the development of an idea as it is expressed and has sway over the minds of other readers. Words are suggestive of associations, ideas and continuity, whether or not the underlying idea is already ripe. The way that the concepts themselves are communicated within a corpus of texts is through their concrete usage in other texts. Although words do not map exactly unto instances of ideas, they do often map unto a perceived continuity in the eyes of the practitioners who deal with the texts of the corpus. We will see how particular uses of words (particular meanings) in a text influence the meanings of subsequent texts and how they were influenced by earlier texts (due to the suggestive power of using the same word across different contexts). As Koselleck argued, when we accept that universals do not underlie our use of language, we must also accept that the continuities in vocabulary are themselves historically substantial causes that give rise to further particular ways of thinking. It is not trivial for Descartes to continue to use certain terms from his scholastic heritage: his reworking of 'causa' should neither be simply taken as 'missing the scholastics' point', nor as 'simply introducing new ideas', but as a specific way to employ the suggested continuity (justified or not) between his own linguistic usages and that of his predecessors.

1.3: Vector Semantics

1.3.1: Linguistic Intuitions

In the introduction, I briefly mentioned that vector semantics derives from a broad linguistic assumption called the distributional hypothesis (Harris 1964), which suggests that word meaning can be found by looking at the company words keep. Word meaning is distributed amongst other words in a text, and to learn a word's meaning, one approach is to investigate its cooccurrence with other terms. This is the basis of computational vector semantics which investigates words by algorithmically operationalizing the 'companies' of words of interest (Gavin *et al.* 2019).

If so, the meaning of words resides at least partly in their usual contexts of utterance. A relational or distributional view does not exclude the possibility that

meaning might also *partly* reside in other things, such as an original act of naming as Saul Kripke would have it (1981), or through universals (Russell 1959/1912). In fact, in Chapter 3, I will argue that a more productive approach is one of semantic pluralism (Wilson 2006; Haslanger 2012) whereby these can all be understood as facets of word meaning, all useful and open to interpretation. However, the fact that meaning resides in the contexts of utterance does bring my position closer to Ludwig Wittgenstein's claim that in many cases "the meaning of a word is its use in the language" (Wittgenstein 1958, sec.43/p.20), or to Firth's adagio that "Words follow life." (Firth 1937/1967, p.24) This view of meaning is particularly helpful for looking at the development of terminology over time. If we assume that a more formalized and consistent terminology constitutes a form of progress, we can also accept that words, before attaining their final form, exerted a different, and therefore historically relevant, sway in the minds of its speakers. Hence, if we can approach these differences through the changes in the distributional features of the use of a word, that will prove to be a limited, though helpful, tool for looking at the development of terminology in a corpus.

However, are there reasons to assume that we can approach the 'use' of a term through its distributional properties in particular? While these techniques do not produce definitions of terms, they grasp facets of the word's usage that coincide with, for example, word associability (McDonald and Ramscar 2001), as we will also see later in Chapter 3. In addition, vector semantics allows for rudimentary computational synonym detection. And, it should not come as a complete surprise that word meaning might be given by distributional linguistic context. To see the connection between linguistic context and meaning, let us turn around the question and see how a given context can already constrain us in expecting certain words to occur. Consider:

John ran out of the kitchen, grabbing a … as he went; the school bus was about to leave.

We can quite easily venture a guess as to the selection of words that might replace the dotted line. Grammatical structure already suggests a noun. The rest of the context (John being in a hurry, the kitchen) suggest that what he grabs (which needs to be small enough to be grabbed) is something needed for school. Most likely, it is food, else, perhaps, it is stationary or some other small item useful for school activities. Perhaps John has less virtuous a spirit and actually grabbed a knife. Now, there is nothing shocking about humans being able to fill in gaps using the surrounding linguistic information. However, this also suggests that certain words (food-words in the example) will be also far more likely to occur in these sorts of contexts than any random other

context. Thus, when aggregating the contexts of all the words that might fit in this sentence, we will also find that all the words that could fit here will be somewhat similar, once all of the contexts of their occurrence are aggregated. Put differently, if contexts determine us to guess that certain (classes of) words occur here, then certain (classes of) words will be similar with respect to their aggregated contexts of occurrence. This means similarities between certain words (and thus conceptual relations) can be extracted (to some degree) from the investigation of word contexts alone. If we are willing to accept that these similarities help us to find conceptual similarities, then their differences will be able to point out conceptual differences as well.

The objects that will eventually be created (i.e., vectors) that describe these words' uses in different works will themselves need to be interpreted in order to extract these similarities and influences. The interpretation of these objects presents significant challenges both to the researcher and to the reader of the research. As Julien Longhi argues (in a broader call for the integration of discourse analysis into the digital humanities), the researcher must provide a thoroughgoing interpretation of the tools used in research:

> [T]he humanities cannot keep using computing simply as a reservoir of tools without knowing how they are actually designed (the "black box"), or why and how they are relevant to their research—otherwise they will lose their own distinctive mark within them. (Longhi 2020, p. 12)

More so, a lack of understanding of the researcher is not the only problem one might run into when using vectors as models of meaning. As James Dobson has recently pointed out, vector representations of texts particularly run the risk of closing off the possibility for interpretation and, in turn are responsible for the loss of retaining a view of the particular phenomena:

> What makes "model work" in the humanities distinct is the critical interest in the possibilities opened up with and foreclosed by each […] level […] of interpretation. To put it another way, modeling in the humanities is subject to forms of critique that aim at both explicit and implicit assumptions while in other disciplines the primary mode of critique operates according to technical criteria. Because of this, it is necessary for humanists, in selecting their tools and data objects, to use those objects and methods that afford the greatest levels of inspection and interpretability (Dobson 2021).

So many choices and decisions go into the coding of a model of a text (and into the algorithms that are used further down the line) that there is an opaqueness of the way that the model has modeled the underlying materials. What is even worse, the

definitiveness of calling something a "vector model" of meaning invokes a sense of simplicity. Similar to the rhetorical dangers of summarizing "economic strength" through a "single" measure like the gross domestic product, so it is also rhetorically dangerous to summarize word-meaning through a "single" measure like a vector model. As soon as a concept is sedimented, the human intuition is to always assume its own capacity for applying the concept in any context.[2] Mark Wilson calls this phenomenon *tropospheric complacency*:

> […] we readily fancy that we already "know what it is like" to be *red* or *solid* or *icy everywhere*, even in alien circumstances […]. But the substantive discoveries of those who have actually probed these environments quickly reveals how shallow and hapless our complacent expectations are likely to prove. (Wilson 2006, p.55)

We like to assume, especially when a concept or measure is in place, that this concept or measure is generally applicable and easily understood. "Of course I know what a vector model of a text is, *I mean, it is a vector model of the text!"*[3] However, as Dobson points out, however helpful our complacency might be in a context where the world itself provides us with "technical criteria," we do not have these to help us shape our conceptual apparatus against our complacency in the humanities. That is to say, we need ways to be more vigilant.

In an attempt to alleviate some of these worries expressed by Longhi and Dobson, I firstly follow Dobson's focus on creating a shared set of assumptions and understandings among readers and author; in the following sections I will give a concise overview of all the decisions (and the rationale behind these decisions) in the construction of the algorithms. This will hopefully enable the reader to critically engage with the results. Not only the inspectability of vectors' entries themselves (that Dobson focusses on) but also a thorough understanding of the construction of the vectors need to be made available for every step in the process. Secondly, as will become clear, decisions in the algorithmic development process directly interlink with the goal of the research itself, hopefully constituting a "[…] co-construction of objects, knowledge, and tools […]" (Longhi 2020, p.12) between conceptual history and computational

[2] Complacency occurs irrespective of whether or not the people who originally introduce the term themselves intend the term to replace a more complex group of terms and measures. Some economists might have intended GDP to be a wholesale reductive measure for economic strength, yet some will not have intended it to be as such. Irrespective of these intentions, there will be a rhetorical force to assume simplicity.

[3] In addition, tropospheric complacency is very useful for the *begriffsgeschichtliche* approach, as it is one of the ways to capitalize on the causal efficacy that "the same word" has on our mental lives.

semantics, planting the humanists' distinctive mark on the methodological procedure. Finally, to prevent (to the extent to which this is possible) invoking tropospheric complacency with regards to the concept of meaning, I actively resist the idea that there is a *correct* way of modelling the meaning of words in texts. This does not mean that there can be no reasons to prefer certain ways of modelling meaning over others. However, at all times, I stand by the idea that the meaning of meaning is itself multifaceted (which I will substantiate and make productive in Chapter 3). As such, different models might be able to capture different facets of meaning and it might also be the case that none of them capture all of the facets of word meaning. We might desire a computational *cure-all* for modeling word meaning in texts. But there is none, if only because there is no singular sense of word meaning for some single approach to attach to.

1.3.2: Vector Semantics – the State of the Art

In the next section, I explain the methods I use throughout this dissertation in order to extract models of meaning for words in a philosophical work. Before I turn to these, and in order to help the reader critically investigate the eventual results, I need to clarify the relation of these methods to the current state of the art for semantic extraction.

Vector semantics, or latent semantic analysis (LSA), has first been developed in the 1980s (Iezie and Celardo 2020; Deerwester *et al.* 1990). Since then, many other methods, including methods that specifically provide access to word meaning, have been developed. The most important developments employ machine learning and allow for embeddings of the word-vectors into low-dimensional models. In the humanities, two methods that have received considerable attention are word2vec (Mikolov et al. 2013) and BERT (Devlin *et al.* 2018). These have also received considerable application within digital humanities, most impressively as methods for tracing semantic changes (Rizollo *et al.* 2009; Hamilton 2016; Tang 2018; Blanke and Aradau 2019; Wevers and Koolen 2020; Tahmasebi 2021; Brown 2022; Armaselu *et al.* 2022).

Vectors are ordered groups of numbers. The location of a number in the vector tells us that vector's value in one specific dimension, or along one specific axis. For instance, a simple 2D-space has two axes, one that tells us about the height (y-axis) and one that tells us about the width (x-axis). I will be using a 'sparse vector approach', which means that, for a single word vector, a score will be calculated for every other word-type in the text. For example, we might have the word-type "chair", and then we will find that "chair" will have a score with the words "table", "the", "printer", "shoe", etc., each of those scores signifying the connection strength between such two words. The whole vector is the vector model of the word-type "chair" in that particular text. A

complete overview of this method is given in the next subsection, but let us first consider its broad dissimilarity to other much used methods.

Firstly, word-embedding approaches (such as word2vec, BERT and others), generate word-vectors that are maximally informative for the prediction of what words are expected to occur in certain semantic contexts. Weights (i.e., the values in the entries of the vector) are learned to have maximally predictive vector representations of a word. Given that they are learned approaches, it is not completely unexpected they generally succeed relatively well for tasks like synonym detection.

Word embedding algorithms define their own axes in the process of generating a maximally predictive model of a word. In general, word embeddings attempt to significantly reduce the number of axes when compared to a sparse vector approach. Whereas in a sparse vector approach there is an axis for every word-type, here a far lower number of axes is generated. The advantages of defining a limited number of axes include both flexibility (the nature of the axes is not defined a-priori) allowing for better learning and computational weight (learning takes many iterations, which will be hard to execute using vectors containing hundreds of thousands of entries). The drawback is that the interpretation of singular entries in the vectors becomes less easy, while the conceptual nature of the axes of the model is less clear to an investigator. This makes the interpretation of word-embeddings problematic. In particular, it is difficult to extract and interpret individual values since the value is now defined in algorithmic procedures that may elude the person who executes the algorithm.

At least one of the methods used in this dissertation (e.g., 'Salience Differentiated Stability', presented in Chapter 3) requires the interpretation of individual values in the vector. That means that for the method in Chapter 3, I could not work with embeddings, but had to work with sparse vectors. Had I used embeddings to define the similarities, I would have needed to switch from embeddings to sparse vector semantics in the case of that particular method. Instead, I have opted for consistency in the application of methods for extracting measures of meaning and semantic closeness throughout the dissertation.

1.4: Algorithmic Details

1.4.1: Co-Occurrences and Windows

The method is based on considering the contexts of word-types[4] (by looking at what word-types surround them) and saving that data in a proper data-structure (called a list of vectors, or a matrix). Word-types (WTs) will be represented *as* the other words that they co-occur with and the counts of these co-occurrences. That is to say that one particular word will be modeled by a list of values that indicate how often that word co-occurred together with other words. The 'company' of a word will then be made up of all the times that word occurred and the other words that it co-occurred with.

First one must get the basic information one needs from the text(s). To do so, we must decide for every occurrence of a particular word *which words do and which do not* count as having co-occurred with it. This is done by introducing the idea of a 'window'. In practice, one places a window over the found word and all other words that fall within that window. A window has a size *n*. Here, *n* signifies the number of words that we look at on both sides of all the occurrences of the word-type investigated. For instance, let's say we choose a window of size 4, and consider the following sentence:

The movement towards digital hermeneutics is fraught with difficulties, but movement is never without difficulties.

One can derive a representation of this sentence in terms of relative closeness of word-types. There are twelve different word-types in the text. For each word-type, we can ask how often each (other) word-type occurs (given the particular windowsize of four words). Table 1.1 below provides the values derived in this way (the first column shows how many occurrences of the WT occur in total):

[4] A word-type is the type of all words in a text that have the same lexical representation. The two words "nature" and "cause" represent two word-types "nature" and "cause", but the two words "philosophy" and "philosophy" represent only one word-type.

#	WT	The	Moveme	towards	Digital	hermene	is	fraught	with	difficultie	but	never	without
1	the	1	1	1	1	1	0	0	0	0	0	0	0
2	movement	1	2	1	1	1	2	1	1	2	1	1	1
1	towards	1	1	1	1	1	1	1	0	0	0	0	0
1	digital	1	1	1	1	1	1	1	1	0	0	0	0
1	hermeneutic	1	1	1	1	1	1	1	1	1	0	0	0
2	is	0	2	1	1	1	1	1	2	3	2	1	1
1	fraught	0	1	1	1	1	1	1	1	1	1	0	0
1	with	0	1	0	1	1	2	1	1	1	1	0	0
2	difficulties	0	2	0	0	1	3	1	1	1	1	2	1
1	but	0	1	0	0	0	2	1	1	1	1	1	1
1	never	0	1	0	0	0	1	0	0	2	1	1	1
1	without	0	1	0	0	0	1	0	0	1	1	1	1

Table 1.1: Example of construction of a co-occurrence matrix

Table 1.1 is a matrix-representation of the contextual information in the text. Each of the rows is a vector (i.e., there is a vector for each word-type) in a 12-dimensional space (where every word-type in the text is a dimension). It is important to note that the windowsize directly impacts the nature of the results of the matrix-representation of the text. There is a strong case to be made that taking different values for the windowsize can in many ways be used to extract not better or lesser results, but properly different results from the text.[5]

However, these raw counts are, on their own, not particularly informative. They need to be transformed so that we can extract values that indicate how strongly two word-types are connected. These values should not directly be influenced by the total occurrences of certain word-types. We see in the above matrix for example that 'movement', 'is', and 'difficulties' all have higher total co-occurrence counts than the other words – a direct consequence of their own higher frequency. However, it is not so that by occurring more often, a WT is necessarily more connected to more types of words in interesting ways. Thus, we need to transform these raw count-scores into a score that is unaffected by total frequency of word-types. For this, I have used and will now introduce the measure *pointwise mutual information (PMI).*

1.4.2: Measuring: Pointwise Mutual Information

Each of the pairs of word-types needs to be scored – or, their connectedness needs to be measured – based on the above data. The way to do this is by extracting both the number of times they have co-occurred and how many instances of the word-type there were in the text. The method I will be using is *Pointwise Mutual Information* (PMI).[6] PMI measures the chance of finding a word-type y within a window around another word-type x (within a chosen windowsize) in the investigated text, divided by the chance of finding y in the whole text. The idea is that related words should be found

[5] For example, the problem with a very small windowsize is that it starts picking up on syntactic relations more so than semantic relations (verbs will generally be scored lower with one another due to the syntactic restrictions on following up verbs with verbs for example), meaning windowsize is not just an optimizable parameter, but one that can be tweaked to identify different features that may prove to be of interest. I have followed a windowsize that (very roughly) is small enough to approximate a 'sentence length' window, while being large enough to smooth out some of the syntactical connections. However, the choice of twelve over, let us say, fifteen, is somewhat arbitrarily made here. Other variations are also available, see for example de Bolla *et al.* 2019, p. 375-378.

[6] Introduced for applications in linguistic analysis by Church and Hanks in *Word Association Norms, Mutual Information, and Lexicography* (1989). Used and discussed further in for example Bouma 2009.

disproportionately in each other's windows.[7] The overall chance of finding y indicates a regular proportion. I take the logarithm of this value in order to make the results better suited for vector calculus later. I write small x for the set of instances of x itself and capital X for the windows around instances of x. Notice that the different windows of X might overlap. In this case, the same word-token will be counted twice or more. Hence X should be seen as the disjoint or indexed union of the windows. The formula for PMI reads:

$$PMI\ (x, y) = log_2 \frac{P(y \in X)}{P(y)}$$

Equation 1.1: PMI in terms of probabilities

This provides the average of the chance of finding a token of y in a window near a token of x, divided by the overall chance of finding y in the text. The fraction can only be a positive value (both denominator and numerator are positive), but a log of a value between 0 and 1 gives a negative value. If the two word-types are fully independent from each other, we would see that there is no difference in the chance of finding x and y in window-proximity to each other in our actual text, compared to the hypothetical situation where they have no actual relation – i.e., the fraction will then give as a result 1. Log(1) = 0, so PMI scores above 0 should be read as indicating a positive correlation between the two word-types in the text, whereas scores below 0 indicate negative correlation, and 0 itself indicates independence.

Computationally, the chance P(y) is simply the instances of y divided by the total word count. The chance P$(y \in X)$ is found by counting each instance of y within the window of an instance of x, where the same y may be counted more than once when it appears in more than one window, divided by the size of the disjoint union X of all the windows, which will always be the windowsize multiplied by the amount of times x appears in the text.

[7] The description given here is analogous to methods of finding out how two subsets of a probability space are correlated. There, the normal procedure is to divide the chance of being in both by the chance of being in both under the hypothesis that they are independent: P(x, y)/P(x)P(y). If the result is 1, they are independent, if higher, the two sets are positively correlated with higher numbers indicating stronger correlations; and, if lower, they are anticorrelated, with lower numbers indicating stronger anticorrelation. Here, I use the same idea albeit slightly complicated by the fact that I am working with windows around tokens of x, and that instances of y may be counted multiple times. In most formulations of PMI (Church and Hanks 1989), the notation mimics more closely finding correlations between subsets of a probability space; computationally, I do the same thing as these authors.

$$\frac{P(y \in X)}{P(y)} = \frac{\left(\frac{|y\ found\ in\ windows\ around\ x|}{|x| * window\ size}\right)}{\left(\frac{|y|}{Total\ words}\right)}$$

Equation 1.2: PMI where the probabilities are unfolded

For example, when we consider the matrix I gave above, we can see that the score for PMI('is', 'with') with a windowsize of four, is given by the fact that we find 'with' around 'is' twice, that 'is' occurs twice itself, that 'with' occurs once and that the entire text consists of fifteen words, giving us:

$$log2\ \frac{\frac{2}{2*4}}{\frac{1}{15}} = log2\left(\frac{1/4}{1/15}\right) = log2(\frac{15}{4})\ = 1.91$$

Equation 1.3: Example of a PMI calculation

When the corpus is only a single sentence, PMI does not yet pick up on any significant semantic properties. However, as we will see later on, when the number of sentences and words grow the situation becomes more interesting.

1.4.3: Deriving Collocates from Vectors

So far, we have looked at the basic representation of relations of strong connectivity between words in a text. A word-type of interest is scored against every other word-type in the text by counting the co-occurrences and then applying the PMI measure to these values. This whole vector can then be taken to be our model of the distributional meaning of the word. This is the sparse vector model of the word's meaning. Its sparsity consists in the vector containing many 0's, as a word-type will generally only co-occur as much as once with a small subset of all available word-types in the corpus. For these other word-types, which we have found next to a word of interest exactly 0 times, we find a PMI value of 0. As described above, the state of the art has moved on from using sparse vectors to using dense vectors, where the number of axes in the matrix is reduced dramatically, but in such a way as to minimize loss of information (Mikolov *et al.* 2013; Devlin *et al.* 2018). However, besides 'densifying' the vector, other further operations can be applied to this whole sparse vector to derive slightly differentiated models of the word's distributional meaning. One of these is the extraction of collocates. The extraction of collocates aims at finding word-types with a particularly strong connection to other word-types in a text or corpus. This is done by asking of two potentially connected words whether their PMI score exceeds threshold value T.

For example, we might expect there to be a particularly strong connection (a PMI exceeding T) between *'causa'* and *'efficiens'* in some early modern philosophical texts. Or, more contemporaneously, we might expect that in a corpus of American newspapers the word-type "Donald" will be very strongly associated with the word "Trump", or, maybe secondarily, with "Duck". These potential examples immediately show us that *the nature of the relation* between the two collocates is not given by the fact that they are collocated. However, for someone versed in these corpora by close reading, the reason for their relatedness will be somewhat easily seen; 'causa efficiens' is a subspecies of 'causa' which grows in importance over the course of the 1600s and really tells us something about the concept of 'causa'. Whereas "Donald" and "Trump" does not really tell us anything conceptually about the name "Donald" (as Mr. Trump is only one of many people named Donald) but it does tell us that within that corpus one of the most prominent people named "Donald" is Donald Trump.

Collocates can be extracted in many ways, but let us consider the case that makes use of PMI (although another normalization measure might be used as is the case for the creation of the sparse vectors). In such a case, for a particular word-type of interest, we might ask the algorithm to return to us all words that are very strongly connected–that is, that come out as having a very high PMI score. Collocate analysis is applied by researchers to be able to find qualitative results instead of purely quantitative results when using vector semantics.[8] The advantage is that whereas a whole sparse vector might be in principle investigable (by looking at the individual values in the vector), in practice it is not, as there are way too many of these values. A list of collocates, however, that is found can be interpreted in qualitative terms by a researcher along the following lines: this list of words are the words that are particularly strongly connected with the word I'm investigating. Since the list is short enough, interpretative work can reasonably be applied to these results. Indeed, one of the main advantages of doing collocate extraction in historical research is to have a grasp on some qualitative and interpretable data.

As an example of how the interpretation of collocate extraction could work, let us consider two paragraphs, one from Margaret Cavendish's 1668 *Grounds of Natural Philosophy* and one from Hugh Hamilton's (1729 – 1805) 1774 work, *Four Introductory Lectures in Natural Philosophy*:

[8] For examples and applications of collocation analysis, see Gavin *et al.* 2019, Brezina *et al.* 2015 and, for a particularly influential application, see de Bolla 2013.

Cavendish 1668:

Though every Self-moving Part, or Corporeal Motion, have free-will to move after what manner they please; yet, by reason there can be no Single Parts, several Parts unite in one Action, and so there must be united Actions: for, though every particular Part may divide from particular Parts; yet those that divide from some, are necessitated to join with other Parts, at the same point of time of division; and at that very same time, is their uniting or joining: so that Division, and Composition or Joining, is as one and the same act. Also, every altered Action, is an altered figurative Place, by reason Matter, Figure, Motion, and Place, is but one thing; and, by reason Nature is a perpetual motion, she must of necessity **cause** infinite Varieties. All the Parts of Nature have Life and Knowledge; but, all the Parts have not Active Life, and a perceptive Knowledge, but onely the Rational and Sensitive: And this is to be noted, That the variousness, or variety of Actions, **causes** varieties of Lives. For, as the Self-moving parts alter, or vary their Actions; so they alter and vary their Lives and Knowledges; but there cannot be an Infinite particular Knowledge, nor an Infinite particular Life; because Matter is divisible and compoundable.

Hamilton 1774:

As knowledge of the operations of Nature, and their **causes**, is not only entertaining to the mind, but capable of being usefully applied to practice, in providing for the ease and convenience of life; it must seem surprising that Natural Philosophy should have made so very inconsiderable a progress in the world, as we find it had done about a Century ago. This must have been owing chiefly to the wrong methods by which it had been cultivated before that time. For, till then, philosophers did not pay a proper attention to experiments, but employed their sagacity in inventing systems and contriving Hypotheses, by which they might explain the operations of Nature. They of latter times have more wisely chosen to build their philosophy on the solid foundation of facts and experience. The method, which they happily pursued, consists in making a number of accurate experiments and observations, and-from thence collecting what those powers and principles of motion are which really obtain in Nature; and in explaining the phænomena, or natural appearances, from those manifest principles assumed as **causes**; and in proving their explanations to be true by shewing, from mathematical reasoning, that the **causes** assigned are adequate to the effects ascribed to them.

Hamilton is employing a broadly Newtonian approach to natural philosophy and chides earlier philosophers for inventing causes as hypotheses without experiments to back up that the causes are actually adequate to explain the effects they are supposed to explain. Cavendish's causes in this paragraph function as explanations for the occurrence of broad properties of the world, "*[nature] by necessity causes infinite varieties"* and "*variety of action causes varieties of lives"*. These causes don't exactly seem hypothetical; however, they also denote conceptual relations that allow inference from one principle of nature to another by reason alone. Now, the question is, can we recover the above reading from the different lists of collocates I extract from these two texts?

These texts both use the word 'cause' (or 'causes'). If we want to see how we can find the collocates of 'cause' from these (admittedly short) pieces of text, we first need to prepare the text by lemmatizing (more on the details of this process in 1.5.5). We would get the following reworked texts, that have now turned all terms into their root form (and removed singular letters):

Cavendish 1668

though every selfmoving part or corporeal motion have freewill to move after what manner they please yet by reason there can be no single part several part unite in one action and so there must be united action for though every particular part may divide from particular part yet those that divide from some be necessitate to join with other part at the same point of time of division and at that very same time be their unite or join so that division and composition or join be a one and the same act also every alter action be an alter figurative place by reason matter figure motion and place be but one thing and by reason nature be perpetual motion she must of necessity **cause** infinite variety all the part of nature have life and knowledge but all the part have not active life and perceptive knowledge but onely the rational and sensitive and this be to be note that the variousness or variety of action **cause** variety of life for a the selfmoving part alter or vary their action so they alter and vary their life and knowledge but there cannot be an infinite particular knowledge nor an infinite particular life because matter be divisible and compoundable

Hamilton 1774

as knowledge of the operation of nature and their **cause** be not only entertain to the mind but capable of be usefully apply to practice in provide for the ease and convenience of life it must seem surprising that natural philosophy should have make so very inconsiderable progress in the world as we find it have do about century ago this must have be owe chiefly to the wrong method by which it have be cultivate before that time for till then philosopher do not pay proper attention to experiment but employ their sagacity in invent system and contrive hypothesis by which they might explain the operation of nature they of latter time have more wisely chosen to build their philosophy on the solid foundation of fact and experience the method which they happily pursue consists in make number of accurate experiment and observation and from thence collect what those power and principle of motion be which really obtain in nature and in explain the phænomena or natural appearance from those manifest principle assume a **cause** and in prove their explanation to be true by shew from mathematical reason that the **cause** assign be adequate to the effect ascribed to them

For both of these texts we can now ask for a particular window-size (for example, five), and for a particular minimal PMI-score (for example, six) what the collocates of ‘cause’ are for the two texts. This is done by generating vectors for both texts as was done in

table 1.1, and then, for the two 'cause' vectors, transform the co-occurences to PMI-scores. Finally, the high scores are extracted as collocates:

	Cavendish	**Hamilton**
1	necessity	adequate
2	she	assign
3	variety	assume
4	variousness	entertain
5		explanation
6		manifest
7		mathematical
8		only
9		prove
10		reason

Table 1.2: Collocates in the Cavendish and Hamilton excerpts, using windowsize 5, minimal PMI of 6

Although we must be careful in interpreting these results (the collocates extracted are now very sensitive to small changes in phrasing due to the low number of times 'cause' occurs in these short texts), the lists of words already signal that Cavendish and Hamilton are associating 'cause' with something else than the other author. Necessity vs. adequate is a nice summation of how the two thinkers have different aims for what a cause is in nature and natural philosophy. Whereas in this excerpt, for Cavendish, to cause something to happen is done by *necessity* (and might be known *a-priori* through reasoning alone), for Hamilton causes are mere hypotheses, that need to be *adequate* for the explanation of facts and observations made through experimentation. Whether or not these bits of texts are sensible models for Cavendish and Hamilton, it is clear that the collocates give an insightful 'summary' of the contexts of occurrence of the term 'cause' in these excerpts. If a similar list of collocates would derive from larger swathes of texts for these two authors, this could potentially confirm the quick survey above.

To return shortly to the technicalities of collocate extraction, for my current purposes, and for comparative purposes in Chapter 3, it is important to see that the results from the collocate analysis can be understood as an operation that has been applied to the sparse vector results. That is to say, the list of collocates can be obtained from the results found in the sparse vector by a few simple steps. Firstly, consider that the list of collocates is implicitly a vector containing only 1s and 0s. The 1s stand for the word-types that did end up in the ultimate list of collocates, the 0s stand for all the word-types that did not. We need a transformation rule that turns all the values in the sparse

vector into either a 1 or a 0. We can generate one by noticing that collocates are picked out only if a word-type has a 'high enough' PMI value, which is decided by the threshold *T*. Hence, we find the transformation rule, for sparse vector *V*:

$$\forall_{xin\ V} \begin{cases} x = 1 \mid x > T \\ x = 0 \mid x < T \end{cases}$$

Equation 1.4: Transformation rule for sparse vector to list of collocates

Equation 1.4 is a simple rule that tells us about the relation between collocate-based results and sparse vector results, making use of one extra parameter, namely, the cut-off value T which decides whether a word becomes a collocate or not.

This is an important result because it shows that, whatever differences there are between sparse vector-based results and collocate-based results, these differences can be understood by interpreting the impact of these two steps, as will be done in Chapter 3. For now, I have introduced sparse vector models of distributional meaning and collocate lists models of distributional meaning.

1.4.4: Similarity Measures

The two aforementioned methods describe how I propose to extract an approximation of the distributional meaning of terms in my corpus. In the first case, a vector represents a concept of a word-type in a text, whereas the latter case, the list of connected terms is represents a concept of a word-type in a text. In the case of the extracted list of collocates, research often focusses on the qualitative investigation of the results. The vector approach generally does not allow for this and is often coupled with a measure of the similarity between vectors. Extracting similarity scores allows the researcher, for example, to check the stability of terms over time, find synonyms, and discover dissimilarity between terms which are expected to hang together. I introduce a commonly applied similarity measure for vector-representations and argue that there are useful options for measuring the similarity of lists of collocates. These measures will be used throughout the rest of the thesis as methods for checking the similarity of distributional word meaning.

In the case of the vector representation, what we are looking for is actually a measure for *closeness* of coordinates in a multi-dimensional space. 'Dragon' and 'lion' might be similar in how much they co-occur with 'dangerous', i.e., in the dimension 'dangerous', 'dragon' and 'lion' have similar values and are close (see Figure 1.1). If they are close in many dimensions, then the words ought to appear as similar.

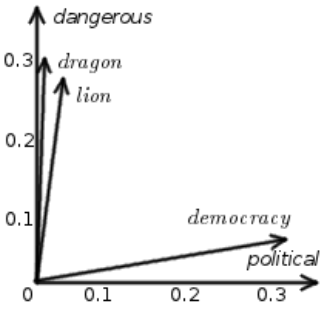

Figure 1.1: Example of word vector distances (image retrieved from https://aurelieherbelot.net/)

A number of different options are available, but one of the more often used measures is *cosine similarity* (Han *et al.* 2012, sec. 2.4.7). Intuitively, the extent to which two vectors are similar is measured by looking at how much they coincide for each of their coordinates. A simple measure for the similarity of vectors is provided in linear algebra by the inner product, or, the dot-product. The dot-product sums the products of each pair of coordinates that lie in the same dimension, or:

$$\vec{v} \cdot \vec{w} = \sum_{i=1}^{N} v_1 * w_1 + v_2 * w_2 + .. + v_N * w_N$$

Equation 1.5: Definition dot-product

Partly, the dot-product does what we want: the more (high) values are shared between two vectors in similar dimensions, the higher the similarity of the two vectors. However, what is counter-intuitive is that longer vectors (vectors with higher values in many dimensions) will *generally* score higher than shorter vectors. However, it is not the case that just because a word-type has more strong connections with other word-types (higher PMI-scores) it should be expected to be more similar to other word-types in general. This problem can be solved simply by normalizing the lengths of the two vectors; in this way, we only measure the similarity in distribution of values across the different dimensions of the two vectors, while negating the influence of their absolute lengths. We get for our similarity measure:

$$\frac{\vec{v} \cdot \vec{w}}{|\vec{v}| * |\vec{w}|}$$

Equation 1.6: Definition of cosine similarity

Linear algebra shows that equation 1.6 captures the same thing as taking the cosine of the angle between the two vectors *v* and *w*, hence the measure's name *cosine similarity*. Higher values are attained when the distribution of values between two vectors amongst all the possible dimensions is similar – or when the angle between the two vectors is close to zero (in addition, for orthogonal vectors, we get a similarity of 0, and, for opposite vectors, a value of -1). This allows our measure to provide values between -1 and 1.[9]

In the case of lists of terms, how to model similarity is less researched because lists of terms are usually not applied to this end. Intuitively, however, what we want to measure is the amount of overlap two terms exhibit in their lists of collocates. The greater the overlap, the larger the amount of connected terms two words share. However, we do not want that word-types that have a larger number of strongly connected terms to be more similar in general to other words (which would happen if we took 'a large overlap' to be signified by a large number of overlapping terms). This needs to be normalized. One of the measures used for these purposes is the Jaccard index, which scores the overlap between the neighborhood sets of items in the following way:

$$\frac{|A \cap B|}{|A \cup B|}$$

Equation 1.7: Definition Jaccard Index

The intersection provides the overlap and the union provides the sense of the 'total' size of the neighborhoods; sharing a large number of terms provides a higher score, the smaller the total sample size of potentially shared terms becomes.

The measure is straightforward in the special case that the neighborhoods have the same cardinality. The sets {E, F, G, H} and {G, H, I, J} will have a Jaccard index of 1/3; the intersection contains two elements (G and H), whereas the union contains six elements (E, F, G, H, I, J). In the case of the same cardinality, we also have the property that complete overlap will provide a score of 1. This breaks down in the case of dissimilar cardinalities. Take the Jaccard Index over {E, F} and {E, F, G, H}. The score will turn out to be a half (two shared elements and four total elements). Thus, the scores will be influenced by the lengths of the lists of collocates. However, on its own this is not a bad thing, as the length of the list tells us something about how much salient connections there are for the word within the corpus. If two terms significantly differ in this respect,

[9] In the case of the scores used in this dissertation, they have been multiplied by a constant (1/0.35) in order to make the numbers more easily readable. The result is that the ordering and relative distance are kept between -1 to 1, but the absolute values will be higher overall.

it is reasonable to take collocate list length into account in the calculations. What we do want to avoid (and what the Jaccard Index avoids) is that words with larger or smaller lists of terms score higher or lower in their similarity scores in general. This is not the case, since the length of the list only comes into play *relative to the length of the list of another word-type with which the similarity is measured.* Word-types with the same, or a similar, neighborhood size will have a higher potential score, but this does not translate into a preference for either larger or smaller neighborhoods to influence the scoring on its own. In addition, the Jaccard index is commutative. It will always tell us that a first word is as similar to a second word as the second to the first. The intuitive symmetry of the similarity relation is maintained.

Let us now apply cosine similarity to our two earlier bits of early modern natural philosophy, the paragraphs by Cavendish and Hamilton. Given that we now have two models for how a word is used (one for each paragraph) we can ask how similar Hamilton and Cavendish are in the use of specific words they both resort to. We might have the sense that their uses of causes are quite dissimilar. In order to compare, let us pick a term that seems to be used more similarly. For this purpose, I select 'nature' which, upon quick inspection, appears to play a similar function in both of these texts as denoting the 'object of study':

Similarity of the 'nature' vector: 0.58

Similarity of the 'cause' vector: 0.30

It seems the intuition we had is borne out (however abstractly) by the cosine similarity of the two 'nature' vectors and the two 'cause' vectors. One potential reason, if we look under the hood of the algorithm, might be the co-occurrence of 'nature' and 'knowledge' in both bits of text, whereas no such salient similarity is available for the two uses of 'cause'.

I have provided an overview of the technical details of the algorithms I will use to implement vector semantics. Vector semantics will be used to extract models of meaning of terms in particular works. Now, what is left is to be done is to describe the materials that will be modeled in this way, namely, the corpus of early modern natural philosophy texts on which my research has been carried out.

1.5: Corpus

In this section, I detail the construction and final shape of the corpus used throughout this dissertation (see Sangiacomo *et al.* 2022b for a complete overview). Firstly, I detail how the inventory was constructed from both expert bibliographical dictionaries of early

modern philosophy and Worldcat.org. Secondly, I discuss the selection of the inventory that was digitized in the process of acquiring machine-readable texts. Eventually, I discuss how the texts were digitized and pre- and post-processed for making them ready for computational use.

The corpus was extracted in the context of the research project "The Normalisation of Natural Philosophy: How Teaching Practices Shaped the Evolution of Early Modern Science." The aim of the corpus has been to provide a comprehensive repository of natural philosophy works published between 1600 and 1800 in the geographical areas of what are now the Netherlands, France, Germany and Great Britain. From an inventory list that contains 2109 works, about 850 have been digitized, and after further vetting, an eventual corpus of 731 works were used. Figure 1.2. offers an overview of the process of distillation.

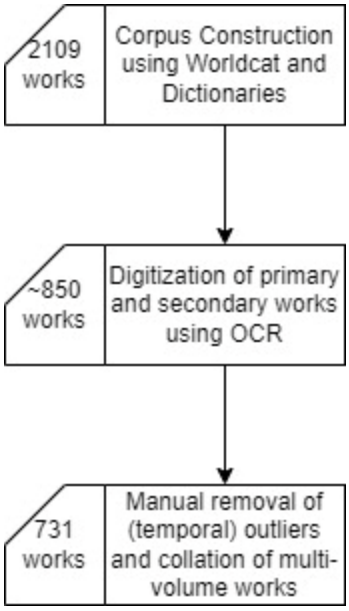

Figure 1.2: Overview of corpus narrowing

The individual works in the corpus play a dual role in the investigation of the development of thought. Firstly, the corpus provides a (selective) snapshot of the state of the debate in this period. Singular works can exemplify what was more generally thought, said and written, in the same way that selecting individual speakers of the English language will tell us something (though not everything) about how that language is being spoken more generally. Expanding this corpus further, one can get a more representative sample of thought and writing style. In this way, a computational model of the corpus is a model that could be interrogated to provide us with information about the period that it covers. Secondly, the corpus contains works that were themselves causally effective in the shaping of natural philosophy. Descartes' *Principia Philosophiae* for instance, is itself not only witness to the state of natural philosophy at the time of publication (1644), but it also shaped its further development. People read, reacted to, objected to and absorbed elements of that work, and the effect can be found in later works included in the corpus. I will not assume that all influences that shape natural philosophy can be found within this specific corpus (other factors can also play significant roles); nor that every work in the corpus was significant in the development of natural philosophy (some might have hardly been read). However, I do assume that some of the driving force in

the development of natural philosophy were the contents of a number of the works in this corpus.

1.5.1: Corpus Construction

The corpus was built using a combination of classical scholarship, digital scraping and annotation. Five voluminous dictionaries, containing biobibliographical information about German, French, English and Dutch philosophers from the seventeenth and eighteenth century have been used (Yolton *et al.* 1999; Pyle 2000; Van Bunge *et al.* 2003; Foisneau 2008; Klemme and Kuehn 2011). There was no seventeenth century dictionary for German authors, and for the French corpus, there was no dictionary for the eighteenth century. In both cases other methods were used to compensate for this lack of resources, as detailed below.

These dictionaries aimed at completeness and, thus, we could use them to select from their pages those philosophers and philosophical works which could be connected with natural philosophy. Additionally, no journal articles or manuscripts were considered, only published books – and only a single edition of those works (preferably the first, whenever available). Works and authors were considered based on their corresponding entries in the dictionaries and annotators (both specialists internal and external to the team) decided whether (and to what extent) the works in question should be regarded as systematic works of natural philosophy.

There were two categories that annotators needed to judge on: (1) Whether a philosopher is a natural philosopher; and (2) Whether a work of natural philosophy is systematic:

> Early modern natural philosophy is best understood as a field of study and debate, which is covered by teaching practices within an academic milieu at a given moment in time. In this field, three concentric spheres can be distinguished:
>
> Primary authors and works (core area): authors and works devoted to offer a systematic exposition of natural philosophy that could be used to teach it to new generations.
>
> Secondary authors and works (buffer area): authors and works devoted to expand, deepen and elaborate on some accepted systematic exposition linked with the core.
>
> Tertiary authors and works (peripheral area): authors and works that incorporate elements presented in the primary and secondary areas and bring

> them into dialogue with other disciplines, problems or debates. (Sangiacomo *et al.* 2022b)

Furthermore, when deciding what constituted natural philosophy, the selection was made broadly. This is important as natural philosophy itself underwent significant change during the seventeenth and eighteenth centuries. A broad selection meant including, for instance, some works on astronomy insofar as they related to natural philosophy (like, for example, the anti-Cartesian Martinus Schoock's 1660 *Physica Celestis*). In this way, the first version of the corpus could be created – a selection from the five dictionaries generated a list of authors and (1st edition, published) works which were deemed natural philosophical and (to some extent) systematic.

The first version of the corpus, however, had gaps, as the French eighteenth century and the German seventeenth century were missing due to there being no Dictionaries available for these selections, and, in general could not be assumed to be as complete as it could have been. To amend these limitations, we developed a digital methodology based on keyword searches in order to look through *Worldcat.org* (a global aggregated website of library catalogues) for potential works of natural philosophy. This was in essence a two-step process. Firstly, we defined the search-parameters by which the *Worldcat* would then be scraped. Secondly, we executed this scraping and collected the results.

The *Worldcat* allows for a number of types of searching and access, but the most practical was via keyword searching in the meta-data and titles of the works. We selected the most relevant keywords in the titles of the works in the dictionaries. Keywords were extracted from these titles: either single words (unigrams) or particularly informative bigrams (collections of two words) on the basis of the number of times they occurred in the titles. We accepted uni- or bigrams that exceeded a set number (depending on the number of titles already in the corpus). These keywords were used to scrape the *Worldcat*, and delivered a large number of results (86,558). They supplemented the time periods not covered by the dictionaries. However, many results were either irrelevant (keywords like 'physick' being also used for medical practices in the period, as well as in the sense of our current 'physics') or duplicates (due to the *Worldcat* aggregating many catalogues from all over the world).

This meant that a large project lied ahead, namely, the sifting through and eventual annotating of the scraped results. Since the initial number of works was cumbersome, a first round of deduplication was executed computationally using the python library FuzzyWuzzy. By doing this, titles with a high literal similarity were removed or consolidated into a single entry. This did not eliminate all the duplicates but already removed about 60,000 titles. We manually annotated the remaining 27,000

titles for their systematicity and relevance, which also included further deduplication of the results and the assignment of nationality. The process led to a further drastic decrease: 1,175 (of the initially retrieved 86,558) extra results were added to the initial 934 results derived from the dictionaries. There was a significant expansion of the number of titles, but most works across the three languages that could be found via the *Worldcat* were already contained by the dictionaries.[10]

Additionally, the authors were assigned nationalities (based on their entries in the Dictionaries, where the choice was made to decide nationality based on place of birth), the language of the publication (Latin, English or French) and the year the work was published (where possible to find, taking the year of first publication). Where the data lacked this information, it was added via annotation, although many of the results from the *Worldcat* and the dictionaries already included at least some parts of it.

1.5.2: Selection in Digitization

The resulting corpus is a corpus of titles and associated metadata. However, for the analyses I will execute in the rest of the dissertation, I needed to have full machine-readable transcriptions of the works themselves, and not all of the titles had been digitized. A series of parameters dictated whether or not a certain work needed to be digitized. Firstly, primary (systematic) works were given preference over all else, and secondary works were given preference over tertiary works. Secondly, and more arbitrarily, works that had easily accessible scans available were preferred. In order to reduce costs and maximize the number of machine-readable works, only scans already available in the public domain were digitized.[11]

Since many of the results that will be extracted aim to analyze the whole corpus, any selection criteria need to be taken into account in the interpretation of these results. The initial construction methods (Dictionaries, *Worldcat* scraping, deduplication and annotating and only looking at the first edition of the books) shrink the actual natural philosophical book production of the period to what is currently available in libraries about that period (scraping the *Worldcat* and analyzing Dictionaries and disregarding articles and manuscripts). We made a further selection by preferring certain kinds of works (primary) and pragmatically favoring works that already had scans available.

[10] Concerning the differences between the final corpus and what was found in the dictionaries, see Sangiacomo *et al.* 2021.
[11] For further information on the digitization of the corpus, see Sangiacomo *et al.* 2022a.

One worry that might arise, most strongly perhaps with the last selection criterion (as it is pragmatic) is that biases are produced in the corpus (Bode 2018). Undoubtedly there are some. For example, the well-known authors and works from the period will have most certainly been scanned, whereas the same cannot be said of lesser-known figures and their works, as their works will have been better dispersed among libraries. When dispersed among more libraries, works have an increased chance of being scanned by one of those institutions. In such a case, the digital selection does not represent the complete corpus objectively, as the well-known authors represent a larger share of the total corpus. Thus, some works that might be outside of the 'mainstream' natural philosophical schools are unavoidably underrepresented, which may skew the results in favor of the importance of these schools. However, a quick look at the differences between the digitized and the non-digitized corpora shows that a significant part of the non-digitized works are also of scholastic, Cartesian and Newtonian persuasion.[12] This is also a reminder that a quick frequency count of the digitized corpus will not be enough to provide us with an idea of "how much" of the materials is well known in the scholarship, because it will be exactly those works that will have had a larger chance of being scanned due to their greater availability.

1.5.3: Method of Digitization

As noted, the raw input of the digitization process are scans of the works in question. The method for turning such scans into text files that contain the encoded series of characters is called 'Optical Character Recognition' (OCR). OCR is an umbrella term: all OCR machines share the same functionality (turning pictures of texts into the correct encoding of characters and text), but the way the machines achieve the task is not uniform.

Most modern OCR machines use machine learning. By giving the learning algorithm examples of correct and incorrect transcriptions of pictures of text, the machine adjusts its own methods for ascertaining correct transcriptions. Thus, it is unclear to us, humans, how exactly the OCR machine comes to its conclusions. That is not to say there can be no insight as most OCR machines also incorporate measures that show how confident the machine is in its assertion. By comparing scans that deliver low confidence and high confidence a human interpreter can try to see how the machine transcribes the image and see where this strategy is frustrated.

The implementation of the OCR machine used for the digitization of the above-described corpus is complex in itself (see details in Sangiacomo et al 2022a). Here I

[12] A number of the works that had no scans available but that were in the corpus for example contained explicit mentions of Newton, Aristotle or Descartes in their titles.

provide only a very limited overview. The machine used achieved about a 90-95% accuracy on our corpus (tested by taking random samples and transcribing them by hand and then comparing the manual transcription to the computer assisted transcription). The inaccuracies were, however, not randomly distributed. Relatively poorly transcribed parts include: title pages, headings, fully capitalized sentences/words, dates and ligature. One of the recurring mistakes is reading spaced out words as a series of singular characters. Below are two pictures of bits of text out of Jacchaeus' *Institutiones physicae* from 1615, and their found transcriptions:

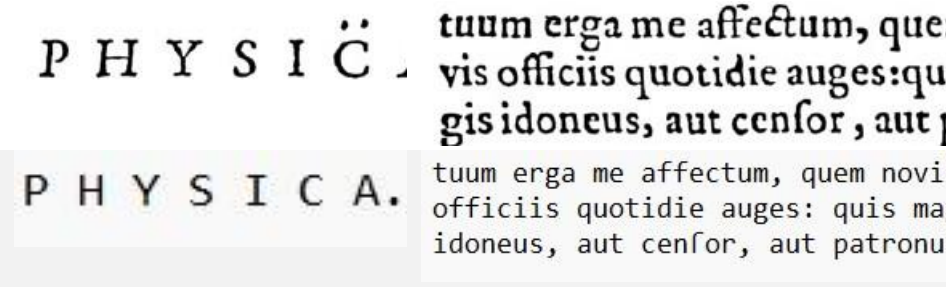

Figure 1.3: Examples of transcribed OCR text

The first, seemingly simple bit of text (PHYSICAE) gets read incorrectly, as the OCR-machine incorrectly reads the space between the characters as proper *spaces* and thus reads seven distinct words ('P', 'H', 'Y', etc.). A 700% inaccuracy if you will! By contrast, the relatively complicated text to the right is transcribed flawlessly.

Although not exactly randomly distributed, a 95% accuracy suggests that most of the methods used are safely applied to this slightly inaccurate transcription. For example, van Strien *et al.* (2020) and Hill and Hengchen (2019) show that for 85-90% correctly transcribed texts, good results can be arrived at more or less irrespective of the method applied. Our own research of the impact of the OCR inaccuracies on collocate extraction shows that, compared with a fully accurate transcription, an 80% and more highly accurate transcription provides close to exactly the same results (Sangiacomo *et al.* 2022a). Indeed, for collocate extraction, it seems that a truly random distribution of errors would lead to significant problems only from 70% downwards. However, the uneven distribution of errors means that the resulting transcriptions will not be suitable for all applications. The analysis of titles and headings will lead to very poor results, and collocates that incorporate the ligature will need to be analyzed more carefully. Also, as single letters occur far more often in the transcription than in the actual work, one should not analyze the use of singular character terms as these are significantly skewed. However, more generally, the accuracy of the OCR method we

used was high, and the semantic methods applied can be expected to generate good results.

1.5.4: Corpus Composition

How does the eventual digitized corpus used in this dissertation look like? Using the OCR method described above, we generated three sub corpora in Latin, French and English, which are machine readable. These are summarized here (divided by language and nationality):

TITLES IN SUB CORPORA	SECONDARY	PRIMARY
German in Latin	106	92
German in French	6	0
French in Latin	33	48
French in French	65	44
Netherlands in Latin	62	45
Netherlands in French	6	2
United Kingdom in Latin	28	24
United Kingdom in English	86	40
United Kingdom in English Electricity Corpus: 44		

Table 1.3: Number of digitized titles per sub corpus

NATIONALITY	No.	LANGUAGE	No.	SYSTEMATICITY	No.
German	204	**Latin**	438	**Primary**	295
French	190	**French**	123	**Secondary**	392
Netherlands	115	**English**	170	**Electricity**	44
United Kingdom	278				

Table 1.4: Corpora divided by nationality, language and systematicity.

The total number of works is 731, which means that we digitized a large part of the total corpus (35%) and more than half of the primary and secondary corpus (52%). Probably, these numbers are slightly higher since for the purposes of this study I have collated multi-volume works into single works, whereas these are taken as separate works in the original corpus. The total digitized corpus can be considered a significant sample of the primary and secondary corpus, and a biased (since tertiary works are not included) sample of the total corpus.

The corpora that are used in this dissertation are those listed under language. The reason is that there are advantages to having maximally large corpora. However, all of the vector semantic methods used in this dissertation are limited for comparison by the language in which they are written, thus making a division of the corpus along the lines of language necessary.

1.5.5: Lemmatization and Character Removal

A final step of preprocessing related to the corpus is that of the lemmatization of the texts. Lemmatizing is the procedure where inflected variants of words are all brought back to single base forms. Since base forms contain most of the semantic information, little is lost. The lemmatization package used was the Python library *CLTK* (Johnson *et al.* 2014) which was applied to the whole Latin corpus, while the NLTK library (Bird *et al.* 2009) was used for French and English. As such, the word-types I investigate include the inflexions of the lemmas, and some word-types are no longer part of the corpus since they have been stemmed into a base form. What is important for the analysis of the results is that Latin lemmatizers attain an accuracy rate of approximately 80% (Burns 2016). However, the accuracy rate will be lower for this corpus as the lemmatizer will find words that have incorrectly transcribed letters difficult to understand. This means that although a lot is won by stemming (words that mean the same are now heaped together in the analysis), one also introduces some inaccuracies. However, unlemmatized results proved to be extremely noisy and made it very hard to parse any semantic relations, especially in the extraction of collocates; as such, I have used a stemmed corpus in all the following chapters.

A final universal preprocessing step has been to remove single character words from the OCRed results. Many capitalized words with large spacing have been incorrectly read as separate letters. Removing separate letters reduces the clutter introduced by the OCR machine.

1.6: A Corpus of Texts as a Network of Semantic Similarities

1.6.1: A Network of Texts by Similarities, or, an Object of Study

The cohesive object of investigation of this dissertation is a number of language specific corpora, which are part of the overall corpus. However, to make the works in the language-specific corpora hang together, the different elements of the corpus need to be somehow related to all the other works in the corpus. Usually, a corpus is tied together either by social factors (works by the same author, whereby unity is established

by providing a portrait of the thinker behind the works) or doctrinal factors (all works within a certain school of thought, which can be summarized as investigation of that school). However, the corpus under investigation lies for significant parts unexamined except for titles of the works (which were investigated for inclusion in the corpus) and incorporates many authors and many schools. As mentioned earlier, citation information is also not easily available. Indeed, the only unifying factor is that all works are works on natural philosophy published between 1600 and 1800. Given this situation, a first approach must be to define a whole that is made up by all these otherwise disconnected works.

A potential route could be the close inspection of all the works, but this route is most likely unfeasible due to the size of the corpus. Another route could be to work with ever more of the metadata that is available about the works and the authors. The aforementioned connection in terms of social factors is being done by colleagues participating in the project (Sangiacomo *et al.* 2022c; Donker, forthcoming). In this dissertation, however, I will tie together all the works by extracting sparse vector models of word meanings. With these models, we can connect works on the basis of the similarity of their semantic profile.

As such, I will construct a network representation of the corpora, in which works will be linked to one another based on their semantic similarity. A network is made up of two entities – nodes (the things to be connected) and the edges (the connectors). Edges stand in for relations, whereas nodes stand in for entities. The nodes will be the different works in the corpus, whereas the edges will be given by the semantic similarity between any two works. Some networks make use of binarized relations: either two nodes are connected, or they are not. For example, when one hypothetically builds a network of someone's followers on Twitter, they could take a person to be connected to all their followers and unconnected to all other people on Twitter. Alternatively, when such a binarized connection is not a sufficient way to model the edges, the edges can be weighted (that is, they have weights assigned to them). For example, if one wants to generate a network of a nation's trading partners, one could use a binary relation (either does or does not trade with country of interest) but a continuous one would be generally more informative, for example based on trade volume between the two countries, which can be expressed as different weights at any given time.

The idea of generating networks using semantic similarities is not new, and analyses of semantic networks have been made in a few cases in philosophy (Zamani *et al.* 2020; Valleriani *et al.* 2022), but are better known in other humanities (Felaco and Parola 2020; Christensen and Kennet 2021; and many others). What is less often done

is generating a multilayered semantic network. In this dissertation, I build multilayered semantic networks based on singular keywords of interest in the corpus.

To build a network that unifies the corpus, I will make use of weighted edges. First, consider the process of connecting one work, x to the rest of the works in the corpus. Work x will have a vector model generated for a particular word of interest, α. X's vector model is taken to stand for the distributional meaning of that word-type α in x. I did this already for the Cavendish and Hamilton extracts, for two words, 'cause' and 'nature'. Now, such a model for α is now generated for each and every work in the corpus (and, thus, for each node in the network). Using cosine similarity as introduced above, every other work in the corpus is compared to x via the meaning of α. The resulting similarity score is now taken to be the weight x has to some other work in the corpus. Assuming (for simplicity's sake) there are ten works in the corpus, now work x has nine similarity scores calculated, with each of the other works, which connects x with differing strengths to the rest of the corpus. The process is repeated for each of the works in the corpus, until every pair of works is now connected by the similarity they have in the usage of word-type α. This process results in a 'fully-connected' network (there is an edge between every pair of nodes) but these results significantly differ in the connective strength of each edge. The resulting network is a representation of similarity relations among the whole corpus indexed on a singular word's meaning, and can now be investigated in its own right or be further enriched.

It is important to note what these nodes and edges are supposed to stand for. The nodes are the individual works *and the vector describing their use of a single term.* The edges describe the similarity between these vectors, that is, how differently the two works are in the distributional meaning they attach to that same word. I assume that a single work of philosophy can attach its own, completely idiosyncratic meaning to a specific term by using it differently. As John Firth states it in *The Tongues of Men*: "Each Man his own Babel!" (1937/1967, p.23). What is produced in the network then is how each work's own idiosyncratic Babel compares to the ones built by his neighbors

1.6.2: Non-Word Indexed Summary Layers

Given that we can generate multiple network representations of the corpus, one for each word-type of interest, we still lack a more unified and generalized network that can stand for the broader semantic profile of the corpus. Although the word indexed method is very suitable for the investigation of singular word-types and their properties in the corpus, it is sometimes cumbersome to investigate the entire corpus for its similarity properties for every word-type. For this reason, we must also recover a generalized similarity score from the word-indexed results.

If we can decide on a particular set of word-types as particularly informative, we might also be tempted to simply take into account all of the different results achieved for these word-types and aggregate them. One common way of aggregating the layers is by creating a multi-relational graph, where multiple edges can exist between two nodes and where each of these edges is labeled with the relation it denotes. The multi-relational graph, however, remains difficult to parse for a human investigator, as it only simplifies visually but does not truly reduce the results. Therefore, I use a more reductive method for achieving a 'summary layer'.

The summary layers are generated by averaging over each of the edge scores and taking the average score for this edge. The added benefit is that each of these edges is provided not only with a summarizing average score, but also with an average divergence of the average for each of the sublayered edges. The divergence score tells us whether the edge in question varies a lot when we switch between specific words that are investigated.

The advantage of the summary layer is that analysis is easier since less data needs to be investigated by the researcher. However, this is only on the assumption that the summarized scores represent their underlying word-indexed scores. The more extreme scores there are in the word-indexed results, the less representative the average score is of the underlying results. An indicator of how well the summary layer represents the underlying results is the average tie strength (a non-word indexed version of our earlier stability quantity) and the amount of divergence between this average and the population results. Each of the word-indexed layers will have an average tie-strength, and the average divergence from the average tie-strength by all of the connections in the layer. We take the average of these found divergence values for the word-indexed layers, which provides an average divergence across the corpus. This value is indicative for how well a summary-layer represents the underlying results. By comparing the divergence to the average tie strength, we can see whether the divergence is relatively high. For example, if the average tie strength turns out to be 100 and the divergence is 2, then there is relatively little divergence between the different keywords and that means the keywords can be easily represented by the summary layer.

Using these networks as the base objects of investigation in the dissertation opens up a number of helpful avenues for the development of new measures used to investigate the underlying corpus. Specifically, by considering average tie strengths of individual word-layers and the summary layer, we can define a term's *stability*, as I will argue in Chapter 2. Stability will prove essential in finding out how unified the schools of natural philosophy are. Stability returns, in two different ways, in Chapter 3, and will provide a more fine-grained insight into specific terms' semantic functions. In Chapter 5

I define a measure of a work's innovativity relative to its position in these same semantic networks. By considering the works' temporal positions (based on their year of publication), I can extract those elements in the networks that influence their future and that were not particularly influenced by their past. As such, the semantic multilayer networks allow for a coherent object on which many of the measures essential to this dissertation will be built.

1.7: Conclusion

In this chapter, I have offered an overview of the alternative approaches to computational meaning extraction and computational history of concepts (1.2), an overview of the methodology (1.3, 1.4) and of the corpus (1.5) and I have also discussed how to apply the methods to the corpus to build a relational representation of it (1.6). By considering stable lexical units (wordtypes) in relation to a corpus of early modern natural philosophy and using methods for the extraction of word meanings (vector semantics), I will analyze the changes in conceptual vocabulary in natural philosophy between 1600 and 1800 over the coming chapters. I have explained the advantages of my specific implementation of vector semantics on the basis of the implied continuity and clarity that goes with using the same word (tropospheric complacency). People who use the same word suggest continuity (whether or not intentional) and this means that tracing the use of single term maps unto a substantial phenomenon in the development of thought. Additionally, using a non-learned algorithm has interpretative advantages as we may expect and understand the algorithms by a thorough grasp of their functioning. To further facilitate interpretative ability, section 1.4 contained a detailed explanation of the algorithmic setup.

In the coming chapters I consider the different ways in which the similarities between individual works of natural philosophy can be analyzed to show us groups of natural philosophy. Grouping natural philosophers will be the immediate concern of Chapter 2, namely, I will look at how to assess the kind of semantic unity and disunity that occurs internal to, and across, the three major schools of early modern natural philosophy: scholastics, Cartesians and Newtonians.

2: Early Modern Conceptual Stability: Schools, Words and Periods

> "The Grouping of Occasions is the outcome of a common function performed by these occasions […]. The grouped occasions then acquire a unity; they become, for the experience of the percipient, one thing […]."
>
> (Alfred North Whitehead, *Adventures of Ideas* 1933, p.201)

2.1: Introduction

Not all disagreements are created equal. The simplest case is one where we disagree about some matter of fact: you think the train arrives at 10:30, whereas I disagree and claim it arrives 10:35. But sometimes what appears as a doctrinal disagreement is actually one that has to do with how we conceptualize the words we use to formulate the answer. For example, I say that the train arrives at 10:30 and my fellow traveler responds by saying I am wrong: it arrives at 10:29. Here, it might be that we disagree about when the train arrives, but it might also have been the case that we disagree semantically. For example, when someone asks me when a train arrives, I round to the closest 5-minute interval. We do not really disagree about the actual arriving of the train, instead we disagree on what the apt vocabulary for answering the question is. When Kuhn considers the 'incommensurability' between paradigms, he suggests that where a lot of disagreements appear doctrinal, these are in fact semantic (Kuhn 2000, p.44). When semantic disagreements become too encompassing, the ability of people to speak with each other is severely diminished, as they are then talking at cross purposes. At the other end, people might be in significant semantic agreement, in which case they are easily capable of speaking amongst themselves.

It is clear that there is a great array of doctrinal positions taken up all across early modern natural philosophy. Different answers exist to questions like: "What is at the center of the universe/solar system?" or "Does natural philosophy concern itself with causes?" or "Is the world a plenum?". However, it is less clear whether the many different thinkers, within different schools are fruitfully in conversation with each other or simply talk past one another. Recently, scholars have been stressing terminological continuity between scholastic authors and Cartesian and Newtonian thinkers, suggesting that there are many places where what appears as significant disagreement

actually belies a conceptual continuity. For example, there have been discussion about the extent to which Descartes draws from the Scholastics he aims to replace (Flage and Bonnen 1997; Schmaltz 2008); the persistence of scholastic philosophy in the universities throughout the 1600s and 1700s (Heider 2012; Sangiacomo *et al.* 2022b); and in general, different forms of continuity that have been stressed between these three different schools of natural philosophy (Des Chene 1996; Ducheyne 2005). This is in opposition to a standard story about the development of natural philosophy. As an instance of the latter, Gunter Lind suggested in the setup of his study of German natural philosophy from 1700 to 1850 (1992, p. VII-VIII), that the three major schools of natural philosophy are scholastic/Aristotelian, Cartesian/mechanistic and Newtonian. Each of these struggles for dominance and eventually replaces previous schools. In such a general story, scholastics reign supreme in the early 1600s, the Newtonians have taken over at the end of the 1700s, with the most activity of the Cartesians in the middle of the period (Butterfield 1959; Westfall 1971).

In this chapter, I use methods of extracting semantic similarity in order to investigate the internal semantic stability of the three schools of natural philosophy, and the stability (or lack thereof) across them. A general continuist approach to the conceptual development in this period would suggest that the internal semantic coherence of each school should not be significantly greater than the coherence across different schools. In opposition, someone who would insist on the "incommensurability" of these schools' terminology would instead expect high internal stability but low conceptual stability across different schools. If the internal semantic stability of these schools is high, this suggests that the labels scholastic, Cartesian and Newtonian pick out genuine semantic labels that are rooted in the languages of early modern natural philosophy.

In section 2.2, I illustrate more extensively the difference between semantic and conceptual disagreements by taking the cue from the case-study of the Hobbes-Wallis debate about the nature of numbers. With a grasp of conceptual disagreement, I then introduce an operationalization of the conceptual 'stability' of both words and groups of works. I first consider how we can extract the stability of a singular term from a similarity network of a corpus (introduced in section 1.6) and how we can abstract to general conceptual stability of a corpus or of a selection of the corpus. Then I formulate a number of experiments. The results and their interpretation will be given in section 2.3. In section 2.4, I introduce a method designed to leverage stability for the investigation of temporal selections (periods) and execute an experiment to try and extract periods from a specific corpus. The results found in 2.3 and 2.4 will favor a discontinuist view, where the three different schools of natural philosophy come out as generally dissimilar to each other while being internally conceptually stable. In section

2.5, I consider what exactly these results tell us, concluding that they do not preclude an interest in neither continuities or discontinuities across these schools. I illustrate this point by considering Descartes' concept of causality and the extent to which it borrows from his scholastic predecessors.

2.2: Conceptual Disagreement and Conceptual Stability: Terms, Corpora and Groups

Thomas Hobbes (1588 – 1679) worried about the equality $\sqrt{8} = \sqrt{2}^3$ that: "[H]ere the root of 8 is put for the cube of the root of 2. Can a line be equal to a cube?" (Hobbes 1845, p.66). This (and other mathematical claims) led to severe disagreements with John Wallis (1616 – 1703). Such a disagreement can be understood as deriving from both personal inadequacies of (one of) the parties involved, from a conceptual disagreement that underlies their doctrinal disagreement, or from a combination of the two. Understanding the disagreement in terms of mathematical doctrine between these authors leads to a reading where Hobbes appears as a particularly poor thinker. The disagreement can only be understood in terms of Hobbes' lacking intellectual prowess (as the algebraic moves that are needed to show equality seem somewhat easy to execute).[13] This is what makes understanding their disagreement as merely doctrinal an uncharitable reading. As Kristin Heitman puts it in her dissertation about Hobbes and Wallis debates: "[…] historical inquiry *rightly* extends beyond the truth and falsity of mathematical claims to examine the way that individual practitioners understood the problems and recourses before them." (Heitman 2001, p.3) Here, we move away from doctrinal disagreements and demand a holistic analysis, where, to understand the disagreement, we need to see how Hobbes speaks in a way that is misunderstood by a speaker like Wallis. Conceptually, we might already suspect as much from the above short citation. Hobbes associates the meaning of numbers, roots and cubes (the operation) with the meaning of lines and cubes (the geometrical object). In some sense, to disagree with Hobbes, we must first move semantically, to see what he means by the

[13] Despite considering all kinds of reasons for the persistence in error of Hobbes (including conceptual), Douglas Jesseph has to conclude in his extensive analysis of the debate that failure of character is also needed to explain Hobbes' persistence: "To have been mocked and humiliated at the hands of Wallis was, as Hobbes himself confessed, almost more than he could bear. […] His refusal to yield ground was the product of shattered ambition and wounded pride, as well as his sense that he had nothing further to lose if his geometry were to go down in defeat." (Jesseph 1999, p.355-356) For illustrative purposes I focus here on the conceptual differences that allowed (at least early in the debate) for a misunderstanding between Wallis and Hobbes (a 'misunderstanding' that, as Jesseph points out, becomes less and less believable as the debate continued and the respective approaches were well developed).

square root of 8 being unequal to the cube of the root of 2. Nonetheless, to see that, we must understand the disagreement as partly having to do with the conceptual apparatus involved does not imply that there is no doctrinal disagreement or that other factors cannot underly the disagreement.

As it turns out, Hobbes is himself committed to his particular semantic connections due to further theories about the nature of mathematics. Whereas Hobbes proposed a materialistically inspired account of geometry and the rejection of algebra as independent from geometry, Wallis proposed a more heavily algebraized approach to mathematics. As a short commentary by Florian Cajori puts it, "Hobbes' assumption established a cleavage between arithmetical and geometrical processes." (Cajori 1929, p.150) And, as Douglas Jesseph remarks, "The driving force behind this unusual *doctrine* is Hobbes's insistence that all magnitudes are ultimately derivable from the three dimensions of body." (Jessepth 1999, p.145, emphasis mine) It seems that Hobbes understands well that his worries hinge on his broader commitments to, and his conceptual understanding of, numbers and his differing in what he takes numbers to be: "I see the calculation in numbers is right, though false in lines. The reason whereof can be no other than some difference between multiplying numbers into lines or planes, and multiplying lines into the same lines or planes." (Hobbes 1845, p.66). 'Number' (for further reasons) means something different for these two authors and their 'matter of fact' disagreement stems partly from their differing understanding. Their disagreement might be partially explained (and measured) by their semantic disagreement about a particular term, 'number'.

Semantic disagreement can thus be relevant in the development of thought, just as much as doctrinal disagreement can be. Differing semantics attached to words can act as fuel to further doctrinal discussions, as is (to some extent) the case in the Wallis–Hobbes debate. Additionally, semantic disagreement can be quantified using the methods presented in Chapter 1. However, instead of analyzing one debate and the semantic frameworks used by the participants to the debate, I propose to look for conceptual agreement and disagreement across larger groups of works. The expectation would then be that some words will be central to much semantic controversy, whereas others are not. Similarly, one can expect that certain groups of authors exhibit a lot of conceptual agreement, whereas others are more internally fractured. Using the methods introduced in Chapter 1, I propose to investigate in particular the schools of natural philosophy using what I dub their 'semantic stability.' Given that we already know that early modern philosophers generally disagree on many issues of doctrine, I propose to instead look at the measure of semantic affinity they have with each other to describe whether or not they make up a coherent whole.

In section 1.6, I detailed how I can create a network of all the works in the corpus for a keyword, where the connection between these works is based on their term-wise semantic similarity. These layers provide us pairwise information about the similarity of the works' use of a single word, so any measure we use on the network will tell us something about the conceptual unity and disunities of this whole network. What I am initially after is a measure that can help us test whether or not the purported schools of natural philosophy (scholastics, Cartesians, Newtonians) exhibit conceptual stability.

In the analysis of networks, the most commonly used measures are *centrality measures*. Centrality measures are ways to investigate which nodes in a network (in my case, books) are most central to the network. Most often, four sorts of centrality are distinguished; degree centrality, betweenness centrality, closeness centrality and eigenvector centrality. Generally, within social networks centrality measures indicate different forms of importance or power of the authors within the network, as the edges allow for the flow of information thus a central node is capable of exerting significant influence (Hanneman and Riddle 2005).

However, it is less clear that this is the case within these corpora of semantic similarity. Firstly, the corpora span 200 years. Temporality in the analysis of networks is an ongoing research topic, in particular for combining them with network measures (Mattsson and Takes 2021; Myers *et al*. 2023). The conceptual issue is that if we want to think of the edges of similarity between books as routes across which information might have traveled (as I will argue to be the case in Chapter 4), then we need to take into account that the flow of information will only run from past to future (which I will incorporate in Chapter 5). Even assuming the network to be made up of social connections, there still is an issue. If an author is central, this might tell us drastically different things depending on whether the centrality derives from the nodes' low distance to people of the past or of the future. Secondly, the core question to answer here, even assuming a suitable network, or suitable solutions for the temporal issues, will not be answered by centrality. Centrality can point us to nodes in the network that are in a position of power. However, what we want to get is a measure of the conceptual unity of (a part of the) network. Although in Chapter 5 I will extract specific nodes form the corpus based on node-level measures, here we need first a measure to characterize whole networks.

To this end, I introduce my own operationalization of the semantic stability of a corpus of texts. The core intuition is as follows: if we accept that a word can alter its meaning over time, or be used differently across different pools of speakers, we can also ask which words are used more or less differently on average across multiple speakers.

If we were to investigate the works of Hobbes and Wallis, for example, we would expect that the semantic stability of the specific term 'number' would be low between these two authors. We can expand this idea to include more words, and, importantly, more works and authors at the same time. In such a case, we would look at the connections between all the different works. The words that are more stable are then words that have little differences among the speakers. Of course, that a term is generally used stably does not mean that it is unthinkable that there are some speakers that are very divergent in the application of the term; but this difference is then an aberration within a larger group. The words that are less stable are words that have many speakers that differ in the use of the term. The reasons might be multifarious: perhaps the word is simply 'chaotic,' not yet having any stable foundation among most speakers; alternatively, perhaps there are a limited number of competing uses, spread across a few groups. In both cases the word is unstable (and this might be the case even if there are some speakers here and there that are using the term quite similarly). The stability is then a property of the network *of one singular word*. Some words are more stable among the same group of users, whereas others are less so. Ranking these scores will provide us with an overview of what terminology is relatively stable in its application within our corpus and which one is not.

Semantic stability is not affected by chronology. Because the measure considers the whole (sub)corpus, it reflects the stability of a word *across the entire period that the corpus spans*. That a part of the instability derives from temporal distance of different works is to be expected and is a valid part of the actual (in)stability the term exhibits. In fact, because the stability of all the terms in the multilayer network all consider the same corpus, the differences between different words' stability values will not depend on chronology.[14] Additionally, we can investigate stability of a word in a part of the corpus compared with other parts of the same corpus. It is this scalability of application that I will use to compare the stability of different schools and different periods in the corpus.

To operationalize the stability of a word-indexed network (and, thus, of the word itself), I take the average edge-weight of a specific word-indexed network representation of a corpus.[15] The measure itself is relatively simple; we examine the

[14] To be semantically stable does not mean that the term is also stable in how often it is used. A term might be very stable over time but also less and less often used. My method only quantifies the semantics of the term and not its importance. However, all the selected terms occur in almost all of the works in the corpus, as they have been extracted using topic modeling.

[15] In the case of a fully connected and weighted network, like the one I work with here, the most helpful way of conceptualizing the operationalization of stability is as average edge strength. However, it closely resembles the *average degree* network property. Average degree is however

average of the tie-strengths and do not consider any structural features of the network. For example, a 4-node network given by the following matrix:

	Node a	**Node b**	**Node c**	**Node d**
Node a	X	2	10	0.1
Node b		X	2	0.5
Node c			X	3
Node d				X

Table 2.1: Example of a 4-node network for stability exemplification.

would have a stability of:

$$\frac{2 + 10 + 0.1 + 2 + 0.5 + 3}{6} = \ 2.93$$

Equation 2.1: Example of stability calculation in 4-node network.

Generally, for a network we can derive the stability by simply considering all the edge weights and dividing this by the total number of edges:

$$Stability = \sum_{i=1}^{\#\ of\ edges} Weight(Edge^i) \Big/ \#\ of\ edges$$

Equation 2.2: Stability of a network

The average tie-strength is calculated by considering every edge in the network (i.e., every similarity score between every pair of works) and adding those up and dividing by the total number of edges. This means that a high stability score occurs when many works in the corpus use the word in a similar fashion and a low stability score occurs when many works in the corpus use the word in significantly differing fashions among each other.[16]

For any layer of our multilayer network, we can now ask what the layer's stability is. When compared to other layers, the score will tell us what words are used

usually defined only for non-weighted graphs as the number of edges divided by the number of nodes. However, since the network is fully connected and every connection is weighted, average degree comes out to the same value as average connective strength. Even so, the latter brings out the sense of the measure more clearly.

[16] The absolute values of the stability scores have no meaning since the similarity values have been uniformly multiplied so as to be more easily readable – what's important is the occurrence of relative scores of different words or corpora.

more similarly on average across the corpus and which one are thus more stable. What is of particular interest is the comparison of particular word-types and the resulting stability scores; one would, for example, expect that simple words, or centers of relatively little controversy, will have higher stability scores generally while terms of major controversy or development have lower stability. However, these scores will mostly tell us something about the terms. Although this is definitely interesting (and a topic I turn to in the next chapter), what I am looking for here is a way to characterize the general semantic commensurability, not just that of singular terms.

In order to do that, we can use the summary layer of the multilayer network in which the word-indexed networks are individual layers (Pio-Lopez e*t al.* 2021). This summary layer will be the average score of all the word-indexed layers. That means that the stability of this network will give us an overview of the general semantic cohesiveness of the corpus. This, I propose, maps unto the semantic disagreement discussed in the previous section: some groups of authors are more or less semantically similar to each other and we can approach this matter by aggregating how similar they are in the use of terminology that is central to the corpus.

The list of terms that make up the underlying layers is thus relevant to the eventual outcome of this averaged stability score. In order to extract a set of terms, topics have been retrieved from the three monolingual corpora. Topic modeling is a technique that finds patterns in texts on the grounds of generative predictive models such as Latent Dirichlet Allocation (LDA) to extract 'topics' that summarize the themes of the underlying texts (Blei 2003). These topics are themselves made up of keywords, words the texts are centrally concerned with and are central to particular themes (topics) the algorithm extracted. By using topic modeling and then vetting these results manually based on domain knowledge, I defined a list of around twenty keywords per language. As noted in Chapter 1, these terms are lemmatized. The terms used to build up the networks are:

French		**English**		**Latin**	
corp	air	force	place	causa	radius
part	point	body	particle	corpus	deus
chos	soleil	motion	matter	pars	species
natur	forc	time	specie	ratio	forma
dieu	egal	water	surface	moveo	materia
homm	lign	velocity	light	aqua	homo
caus	eau	part	line	locus	anima
matier	rayon	distance	radius	tempus	potentia
terr	mouv	earth	electricity	genus	ignis
raison		reason	sun	natura	terra
		cause	method		
		nature	object		
		fire	experiment		

Table 2.2: Term selection for multilayer network creation.[17]

This list of terms meanwhile only consists of words that were central to the activity of natural philosophy. More terms would result in a more solid average. However, as we will see shortly, the differences in the stability scores of the words differ only by at most 30% from the average they constitute. The average they form seems to be quite solid and representative of the general stability of terms central to natural philosophy. Using these terms, I generated the multilayer networks for each of the three languages and visualisations of their summary layers, which can be seen below.[18]

[17] In Chapter 5, I used the same selection of terms. However, a different selection is used in Chapter 3 (because these results were derived earlier in the research cycle on a smaller corpus, to be detailed there) as well as in Chapter 4 (which is a case study on Anne Conway's work, so I chose a series of different term which are more in line with her specific interests).

[18] The similarity measure used is co-sine similarity, using a minimal word frequency of 2 and a windowsize of 12. It is important to note that the absolute values have no meaning, so any structural difference in absolute value between the two sets of results should be ignored, only the relative scores are of interest.

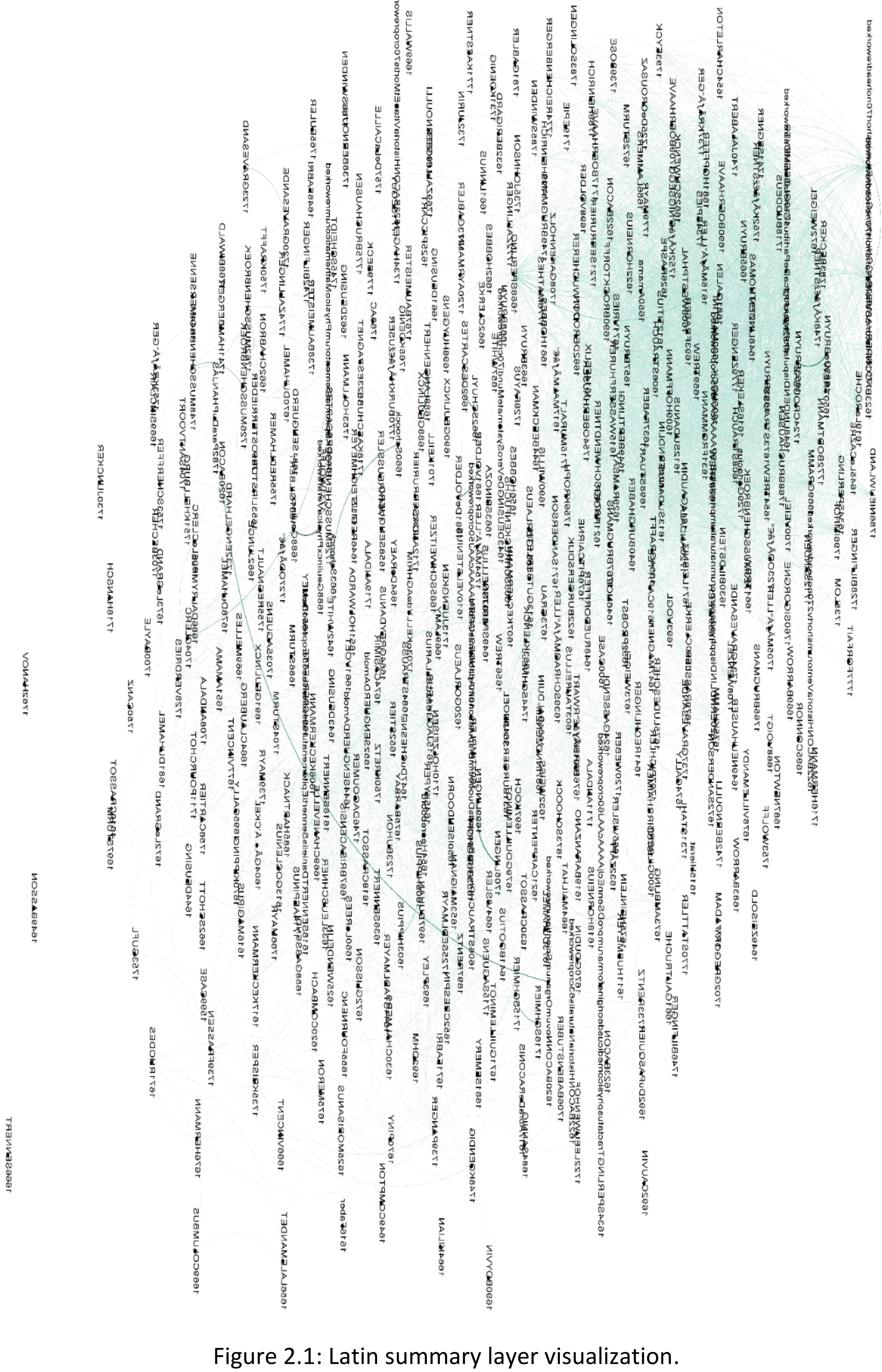

Figure 2.1: Latin summary layer visualization.

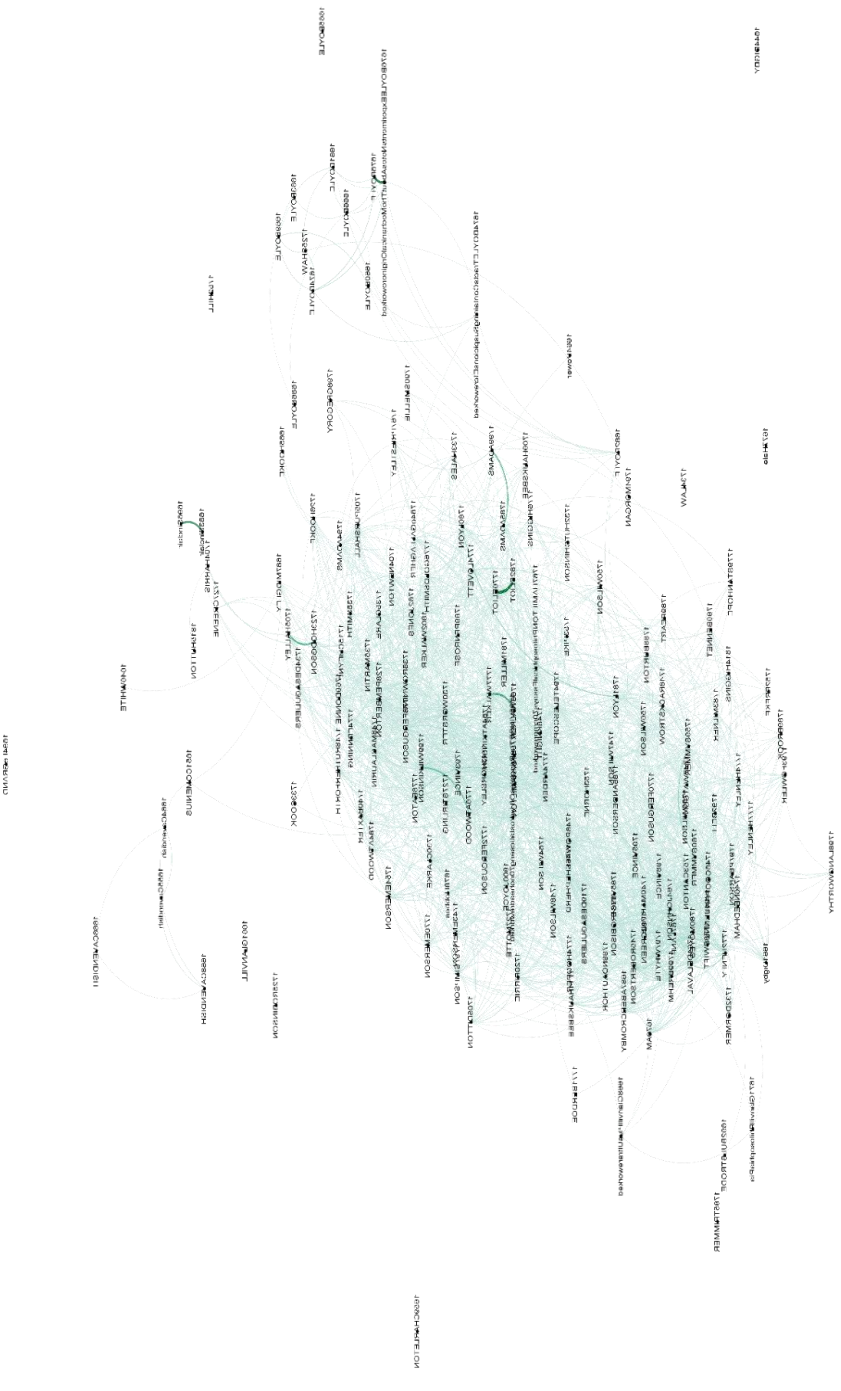

Figure 2.2: English summary layer visualization.

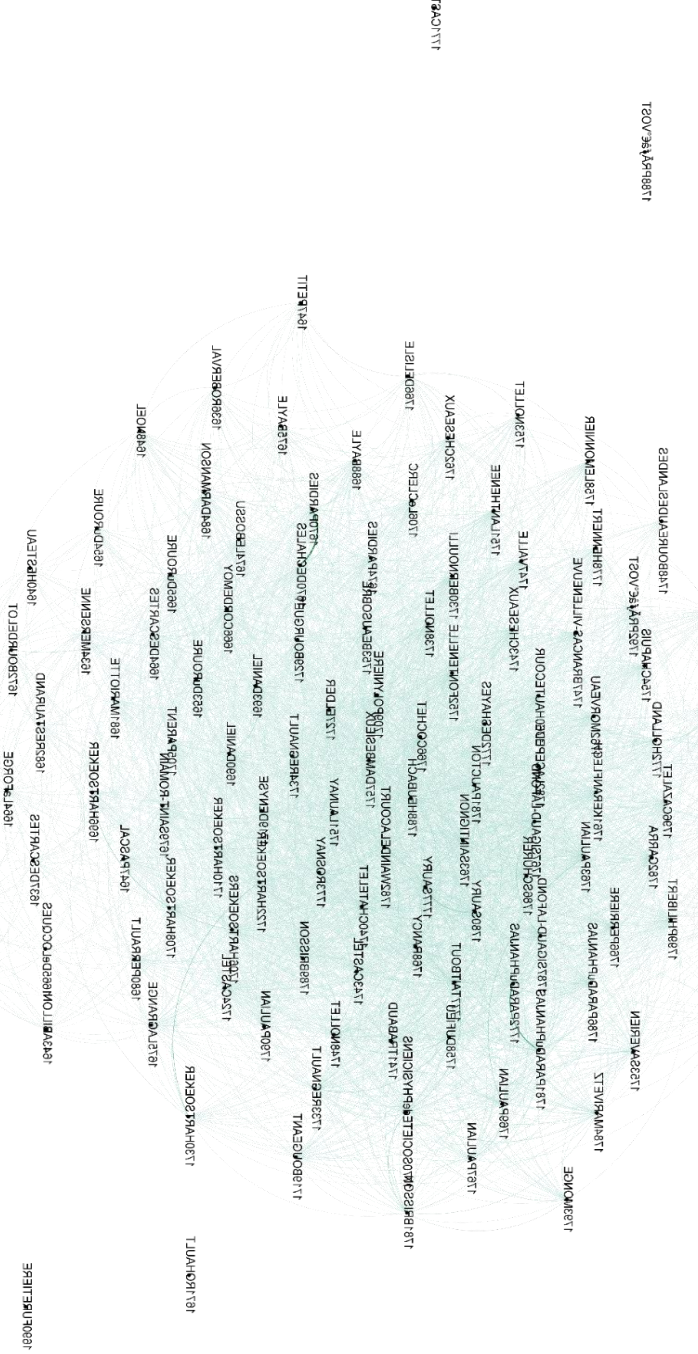

Figure 2.3: French summary layer visualization.

On their own, these visualizations help us to imagine what the method consists of: each of the above works is connected with a variable strength (based on how semantically similar the works are to each other) to all the other works; these connections are visualized as a graph corresponding to each language-specific corpus. Pairs of works that have higher similarity attract each other more strongly topologically, meaning that spatial proximity signals a high similarity between two works . However, for testing more precise hypotheses, I will use stability to express these networks' qualities quantitatively.

The stability scores of these summary layers will provide a measure of the semantic coherence of these corpora. However, the absolute values of these scores are not particularly informative; they become informative when scores can be compared. Instead of asking for the stability of the corpus, I can ask for the stability of certain groups of authors. For example, what is the average connection strength of all Newtonian authors? Such a number would give us an idea of the internal coherence of schools of natural philosophy. Or, what is the average connective strength among all Newtonians and all scholastics? These numbers would tell us something about the measure of semantic continuity that exists between these schools. There are three different sorts of stability scores that I will extract: word-stability, corpus-stability and (inter)school-stability. Before I detail the results of the schools' stability scores, let us first look at the results of the corpus and word stability scores.

2.3: Results

2.3.1: Word Stability Results and Corpus Stability Results

The stability scores for the English, French and Latin multiplexes are extracted and listed in Tables 2.3-2.5. We can see that all certainty intervals are very small (lower than 2), therefore they will be omitted here. The words are ordered from the most stable to the least stable and the final column lists the (positive or negative) percentual difference from the average per word stability to offer a sense of the size of the discrepancy between different words:

Table 2.3: Latin stability scores

corpus	300	12.5%
aqua	299	12.2%
radius	295	10.8%
ignis	287	7.9%
anima	280	5.2%
forma	276	3.4%
moveo	273	2.2%
terra	272	2.0%
materia	268	0.6%
pars	267	0.3%
deus	265	-0.5%
causa	261	-1.9%
potentia	257	-3.6%
natura	256	-3.9%
tempus	256	-4.0%
locus	255	-4.5%
homo	253	-5.1%
ratio	247	-7.4%
species	238	-10.7%
genus	234	-12.3%

Table 2.4: English stability scores

velocity	388	20.4%
sun	362	12.4%
radius	354	9.9%
body	351	8.9%
water	350	8.6%
distance	348	8.0%
electricity	346	7.4%
time	340	5.5%
particle	339	5.2%
line	336	4.3%
motion	334	3.7%
surface	331	2.7%
experiment	330	2.4%
object	328	1.8%
earth	327	1.5%
force	324	0.6%
light	314	-2.5%
fire	305	-5.3%
nature	305	-5.3%
part	303	-6.0%
matter	300	-6.9%
reason	299	-7.2%
place	297	-7.8%
method	294	-8.7%
cause	293	-9.1%
specie	273	-15.3%

Table 2.5: French stability scores

mouv	364	29.1%
corp	347	23.0%
lign	322	14.2%
soleil	321	13.8%
egal	298	5.7%
rayon	293	3.9%
forc	290	2.8%
point	289	2.5%
terr	285	1.1%
dieu	281	-0.4%
part	280	-0.7%
natur	279	-1.1%
chos	278	-1.4%
matier	278	-1.4%
caus	273	-3.2%
eau	265	-6.0%
raison	262	-7.1%
air	259	-8.2%
homm	247	-12.4%

The word stability scores across the languages show a few interesting things. First, there is a group of words, which we might call 'metaphysical,' that are scoring (somewhat) poorly across all the languages. These are words like 'specie', 'genus', 'cause/causa/caus-', 'homo/homm-' and 'natura/nature/natur-'. Some of those also played a role within scholastic thought and get reworked and discussed among the following new philosophical schools. Their instability might partly derive from them getting taken up in very different ways among new schools. At the same time some of the stable terms are terms that might be claimed to be somewhat simple; 'water/aqua', 'sun/soleil', 'earth/terra/terr-' are all terms that have relatively straightforward extensions and, although of course discussed (which is why they were picked up by the

initial topic modelling), do not appear to be targets of particular conceptual disagreement among early modern natural philosophers.

However, there is a second group among the more stable terms. All the languages show that words relating the movement and bodies are relatively stable: 'corpus/body/corp-', 'moveo/motion/mouv-' and 'velocity'. This is interesting as one of the major interests that develop in early modern natural philosophy is that of the local motion of bodies. Some would even boldly claim natural philosophy to be reducible to an investigation of "bodies in motion." (Roux 2017) These terms' stability might derive then from being so central to later schools of philosophy and their activities, and less so in the earlier scholastics, meaning that the term meaning did not necessarily need to be altered significantly. This however disagrees with the fact that the admitted centrality of the terms also made them terms of great conceptual disagreement among practitioners.[19] Our expectations would thus seem to be contradicted: bodies and movement ought to be topics of considerable controversy, yet they come out as particularly stable terms.

Although we can see that semantic stability can grasp unto an intuitive sense of stability (simple terms at the top of the list, scholastic and metaphysical topics of discussion at the bottom), some words appear to be picking up on a different sense of stability than what we would want from this operationalization. It shows also the limits of using stability on its own for the investigation of individual words: a single value is not differentiated enough to characterize all the senses of conceptual stability that we might want to see modeled. For now, I do not address this limitation; but, in Chapter 3 I will make headway into making stability more useful as a tool for the investigation of individual terms by modeling multiple senses of stability. It will be exactly the troubling terms in this list ("corpus/body/corp-", "moveo/motion/mouv-" and "velocity") that can be accounted for by this more sensitive measure and be interpreted fruitfully. For present purposes, however, we leave out the individual term layers and will instead start considering the aggregation of stability scores in the summary layers.

Let us compare the three language-specific corpora (English, French, Latin) for the stability of their summary layers. Additionally, since summary layers are an aggregate of the underlying word-indexed layers, I can also extract the average difference from the mean that the individual layers have. A lower average difference of

[19] A program that set out to explain nature in terms of bodies in motion was all the time plagued by explicit disagreement about what bodies were. Whether bodies are simply extension as it was for Descartes, or whether they should include properties usually ascribed to spirits as for Anne Conway and Margaret Cavendish (Rusu 2021; Georgescu 2021), and whether they were impenetrable and (infinitely) divisible (Roux 2017) were issues that pervaded the program.

a corpus tells us that the spread of scores is more centered around the average. A low divergence tells us to expect less, and less extreme, outliers. The stability and deviation for the three summary layers listed in Table 2.6:

	Terminological Stability	Average Deviation
Latin	265.9	61.5
English	322.2	60.9
French	282.4	62.6

Table 2.6: Terminological stability and average deviation in summary layers.

The deviation that underlies the three corpora is similar, indicating that we are to expect similar differences between the scores of different words and works. The least stable corpus is the Latin corpus, which is also the largest corpus, that incorporates the most scholastics. As we shall see in the next section, of all the schools, the results suggest that the least strongly semantically unified school were the scholastics. Meanwhile, the English corpus (which contains only British works) is populated with the least scholastics, providing a possible explanation for the ordering of the terminological stability of the three languages on the basis of the prevalence of certain schools and their found terminological stability.[20]

On their own, individual term scores and the language-wide stability scores give us a coarse overview of the profile of the corpus. The individual word-stability results will be expanded upon in the next chapter. The corpus-wide results provide a benchmark value against which more precise results can be measured. With these results in mind, we can now move to the main question, related to the purported internal semantic unity of schools and semantic discontinuity across schools.

2.3.2: Schools of Natural Philosophy

In order to extract the semantic stability within and across schools, I will first need a dataset which allows me to tag specific works in the corpus as either Newtonian, Cartesian or scholastic. For the experiment, I use the Latin summary layer and the intellectual affiliations extracted from the dictionaries of natural philosophy (Yolton *et al.* 1999; Pyle 2000; Van Bunge *et al.* 2003; Foisneau 2008; Klemme and Kuehn 2011). In the dictionaries used in the construction of the original corpus, sometimes the school

[20] The stability scores here deviate from the ones found in "Recreating the Network of Early Modern Natural Philosophy" (Sangiacomo *et al.* 2022c). There I did not use a cosine similarity based on sparse vectors (as here) but a collocate similarity approach. I argue in Chapter 3 that these two similarity scores require different interpretations and, as such, signal the stability of different facets of the terminological stability.

affiliation of an author was explicitly mentioned. Those mentioned have been collected during the initial phase of corpus construction, allowing for an incomplete, but well attested, judgement of school affiliation for these authors. Because these annotations are not complete, every node that was not extracted from the above-mentioned sources will be tagged as "unknown". I exclude the French and English layers (as I will also do in Chapter 5) because the number of annotations that was available is lower for these smaller corpora. By tagging nodes with their respective school affiliations, we can ask of every connection between two nodes what sort of connection it is. Let us say that we have only four tags: scholastic, Cartesian, Newtonian and unknown. The tags lead to ten different kinds of edges between the nodes. First, we have all connections among the same school:

- scholastic – scholastic
- Cartesian – Cartesian
- Newtonian – Newtonian

Then, 3 different connections among different schools exist:

- scholastic – Cartesian
- scholastic – Newtonian
- Cartesian – Newtonian

Finally, four connections remain that would include the unknowns (connected to itself and the other three schools). These four categories will be put together into a single value that will function as a control score, which will be corroborated with the whole corpus average.[21] For each of these seven types of edges, I extract the average connection strength, i.e., terminological stability, within the Latin corpus. The results are shown below:

[21] The unknowns might include works that are associated with these schools. However, there is no reason to assume that they will be predominantly populated by some particular school affiliation. Tthe average can still be expected to be between cross-school and inter-school connections, since both will occur within this group of edges.

No.	Connection type	Terminological stability	No. of connections checked	Weighted average stability
1.	Cartesian – Cartesian	332	78	Same school average: 302
2.	Newtonian – Newtonian	309	21	
3.	scholastic – scholastic	292	253	
4.	Unknown-related	266	94836	
5.	Cartesian – Newtonian	265	70	Cross school average: 244
6.	scholastic - Cartesian	258	200	
8.	scholastic – Newtonian	213	140	

Table 2.7: Terminological stability of Cartesian, Newtonian and scholastic edges.

The lack of completeness in annotations results in most scores involving unknowns, which also means that this is the most sensible "base" score, against which to compare the other scores (it is in fact, the same score as the Latin corpus total stability).

The results are very telling. In the final column, there is a very clear difference between same school connections (302 term stability) and cross-school connections (244 term stability). Furthermore, we can also see that each individual same school term stability score is higher than each individual cross-school score. It is not so that a particular school's high internal similarity is pulling up the average of all same school connections up across the board. Same school networks of works are semantically more stable than cross school networks in general. Such results confirm that working within a similar group will also require (and, thus, induce) some conceptual coherence amongst the practitioners. On the other hand, the results show a distinct conceptual discontinuity between the different schools of natural philosophy. What this aspect in turn suggests is that (at least in terms of conceptual stability) the historical labels of 'scholastic', 'Cartesian' and 'Newtonian' do indeed pick out groups of authors that are conceptually akin to each other; and, also, more akin than what would be generated from merely sharing the context of 'natural philosophy' in general (which was the 266 average score we find in the middle of the results).

The results are informative even beyond this partial conclusion. The ordering of the specific same school/cross school scores reveal more about how semantic distance can be generated. The cross-school connections (scholastic–Cartesian, scholastic–Newtonian, Cartesian–Newtonian) are temporally ordered. The connection types with the least semantic distance are also those which have a smaller semantic distance. Cartesians–scholastics and Cartesians–Newtonians are two connection types

linking schools that came up while the other school was well-established. By contrast, there is a very large drop in semantic continuity when looking only at scholastic–Newtonian connections.

Cartesians were forced to deal with scholastics when their school rose to prominence, nicely illustrated by Descartes' own indebtedness to scholastic concepts (Schmaltz 2008). Newton extensively engages with Descartes (Janiak 2019), although somewhat less visibly. However, Newtonians are less temporally and conceptually proximate to scholastics. Newtonians give full-blown development to a mathematical approach to natural philosophy, marking a definite difference in the conceptual apparatus for dealing with the world with respect to the scholastic tradition. To some extent, scholasticism is a less relevant opponent for the Newtonians,[22] meaning that extensive interactions become less important, leading to less and less conceptual fine-tuning and translation between these schools. Thus, the scholastic–Newtonian connections stand out as particularly terminologically unstable.

At the same time, these results also make the case for a continuist story of the semantics of natural philosophy: scholastic terminology is reworked by Cartesians, which is then reworked by Newtonians, until the terminology becomes conceptually unrecognizable to its scholastic origins. So, although we find discrete elements (three different schools), we also find continuity in the way they relate to each other, any one school feeding into the next school's terminology.

The ordering of the same school stability scores paints a slightly less clear picture. The fact that Cartesians are the most stable, followed by Newtonians and then scholastics suggests more conceptual differences internal to scholastic authors. One potential explanation is that late scholasticism arguably contains multiple sub-schools, at least Thomists and Scotists (Dvořák and Schmutz 2019). A quick look at the names that occur in the corpus titles suggests three major figures of authority within late natural philosophical scholasticism: Aristotle, Duns Scotus, and Thomas Aquinas.

To further substantiate the intuition that the lack of unity among scholastics derives from those being a rather large and differentiated group of thinkers, one could repeat this experiment using more fine-grained annotations. However, there is no annotation set available similar to the differentiation between Cartesians, scholastics, and Newtonians. These were derived from dictionaries and expert annotation. In earlier phases of the ERC project, however, explicit mentions of names of authorities (authority

[22] Newtonianism was additionally more present in Britain initially, whereas of all geographic areas, this was where scholasticism was most weakly represented (Sangicaomo *et al*. 2021a), leading to even less need to interact.

acknowledgements) had been extracted from the titles of the works, to further expand on the annotations provided by the dictionaries. The core idea is that references to major figures already play a significant role in the positioning of a work (irrespective of whether the author will eventually oppose or agree with the mentioned authority). This makes such an annotation set of a different nature than the one used above.

However, in lieu of more expert annotations, I repeat the process described in Sangiacomo *et al.* 2022b, for all scholastic authors. I separate the scholastics into three groups: Aristotelian, Scotist and Thomist. Aristotelian key terms by which a work was deemed as such were 'peripetratic', 'Aristotle', 'Octos Libri Physicae', for Duns Scotus I used 'Scotus' and 'Doctoris Subtili' and 'Aquino' and 'Thomisticae' were used for Thomists. Few explicit mentions were found in the title corpus; I found 24 explicit mentions of Aristotle, 5 of Duns Scotus and 3 of Thomism. Such low numbers mean that we need to be careful in the interpretation of the results as they might depend on too few connections being checked. This complete set differs from the scholastic set used in Table 2.6, for this one is based on titles containing references to certain authors and not expert annotation.

To see whether these three sets form more conceptually stable groups than the overarching scholastic group, let us repeat the earlier experiment. I will check all the connections between:

- Aristotelians and Aristotelians
- Scotists and Scotists
- Thomists and Thomists

and:

- Aristotelians and Scotists
- Aristotelians and Scotists
- Thomists and Scotists

As before, if the labels form coherent groups with their own conceptual vocabulary, one would expect higher connective stability in same-school connections and lower across schools. The results are described below in Table 2.8:

No.	Connection type	Terminological stability	No. of connections checked
1.	Thomist–Thomist	343	3
2.	Scotist–Scotist	309	10
3.	Thomist–Scotist	309	15
4.	Same School average	306	289
5.	Aristotelian–Aristotelian	306	276
6.	All scholastics average	289	496
7.	Aristotelian–Thomist	289	72
8.	Cross School average	265	207
9.	Aristotelian–Scotist	245	120

Table 2.8: Terminological stability of Aristotelian, Scotist and Thomist edges.

The picture is a bit less clear than with the earlier annotated schools. However, a number of things come to the fore. Firstly, the average stability of this groups of scholastics based on authority acknowledgements (289) is almost the same as the average stability that was found for the scholastic school defined by expert annotation (292). This finding in general suggests that the two methods of annotating at least map unto each other somewhat well.

Secondly, we see a very clear decrease in cross sub-school connections and an increase in same sub-school connections (265 vs. 306, with the average being 289). This also means that when further subdivided into three sub-schools, the scholastic school almost exactly matches the Newtonian stability found in Table 2.7 (309). This in turn suggests that scholastics, properly subdivided, can attain a similar internal coherence as Newtonians. The ordering of the specific connection types maps unto expectations less clearly. For example, Thomists and Scotists are a cross-subschool connection and, yet, score more highly than the same school average of the Aristotelians. This should be expected to be due to the low amount of works checked since, in the literature, Thomists and Scotists are clearly delineated as sub-schools that antagonize one another in scholasticism (Hoenen 1998; Stone 2006). Aristotelians are the least internally stable of the subschools, but this is to be expected given that we would also find a large number of commentaries under this header (which might include the conceptual framework of the tradition that is commented upon). I propose that scholastics can be fruitfully subdivided, although the highly stable relation found between Thomists and Scotists remains unclear (most likely a result caused by the lack of datapoints).

The semantic coherence of schools of natural philosophy can thus be recovered using a measure of semantic stability. In the meantime, the discontinuities across

different schools are more pronounced. The results of this section broadly agree with the idea that early modern natural philosophy can be subdivided into three schools. The least unified of the groups, scholastics, were further subdivided based on a different sort of annotation set (authority acknowledgements). These results suggested that scholastics are indeed not a monolithic group and could be, from the perspective of their conceptual stability, chopped up into three other groups: Aristotelians, Thomists and Scotists, with the caveat that the lack of data makes it hard to differentiate between an apparent Scotist-Thomist similarity deriving from genuine unity, or from outliers.

The ordering of the three types of cross-school connections shows the importance of extensive interactions for semantic closeness. Actual interaction leads actors to become more and more capable of engaging (or at least translating) the other party. With a lack of interaction may come a lack of linguistic and conceptual 'give and take' that allows for the useful communication of ideas. The more two groups of people are in linguistic contact with each other (through for example, criticism), the more they are forced to make themselves understood by the other party.

All these results might suggest a strong discontinuity between schools of natural philosophy. However, considered otherwise, the results also provide the basis for a more continuous narrative: scholastics are more similar to Cartesians, and Cartesians more to Newtonians than scholastics are to Newtonians. Over time, scholastic terminological associations get picked up and transformed by Cartesians, which get in turn picked up and transformed by Newtonians. The discontinuity becomes apparent when we focus on the internal coherence of these three discrete schools. But the continuity manifests when we focus on the relative similarities between these schools. Scholasticism feeds into Cartesianism, which feeds into Newtonianism, showing a clear development of terminology throughout early modern natural philosophy.

In the next section, one more experiment is conducted, one which aims to test whether periodizing the corpus might agree with the picture where schools of natural philosophy replace previous schools of philosophy. The failure to do so further substantiates the idea that semantic closeness is the product of co-existence and that this co-existence occurred for most of the early modern period.

2.4: Mapping Schools to Periods

Given that we already know these schools to be significantly semantically unified, one might hypothesize that, if the schools followed upon each other and replaced each other, we should also see three semantically unified periods in the corpus. Due to the

fact that most of the works in the corpus are not annotated, such a finding would be a substantial extension of the current meta-knowledge of the corpus.

Descartes publishes his most systematic work of natural philosophy, the *Principia Philosophiae,* in 1644, which immediately provokes reactions in the broader intellectual community. Similarly, Newton publishes his *Principia Mathematica* in 1687 and attracts attention from scholars across the continent. In light of the previous experiment, I expect Cartesians and Newtonians to be semantically unified. Based on this, for the purposes of setting up an experiment, we can additionally hypothesize that the Cartesian and Newtonian schools have distinct starting points, years 1644 and 1687, respectively. With these two assumptions in mind, one would expect that the periods that are characterized by one of the three schools also exhibit a higher terminological stability overall. At the same time, if we do not find a significantly higher stability, then apparently something was wrong with the assumptions. For example, we might expect that philosophers become famous years after their initial major publication. Additionally, the assumption that schools replace each other might turn out to be false.

Testing all the above is somewhat easy and will be done by splitting the Latin corpus into three parts: 1600-1644, the scholastic period; 1644 – 1687, the Cartesian period; and 1687 - 1800, the Newtonian period. I will inquire for each of these segments what the stability is and one would expect higher stability for each of these parts. The results I obtained are detailed below for all the three corpora:

	Stability
Whole corpus	266
1600-1644 (scholastic)	295
1644-1687 (Cartesian)	271
1687-1800 (Newtonian)	266
Weighted average of the three periods	272

Table 2.9: Stability scores for periodized Latin corpus.

The Latin corpus does not show the behavior that we would expect if the periods were mostly made up of their respective schools' practitioners. There is a high stability in the first period (295), which (perhaps) incidentally is very close to the stability of the scholastic school (292) found in Table 2.7. The result suggests that the first period might very well be dominated by scholasticism. However, the two following periods do not show an equally clear increase in stability compared to the Latin average. The second, supposedly Cartesian period is slightly more semantically unified, but nowhere close to the Cartesian unity that was found in Table 2.7. The third period, supposedly Newtonian, is as stable (despite being significantly more temporally restricted) as the whole Latin

corpus (266). This indicates that, the threefold distinction into schools works well in the Latin corpus, but that their accompanying temporal division does not.

It appears that the periods found generally do not map unto the three schools. And this should not be wholly surprising since, after Descartes publishes his *Principia*, scholastics continue to produce natural philosophical materials. In fact, even after the rise of Newtonians, there is still scholarly production from both Cartesians and scholastics for quite some time. This means that the only period of which we might expect to be mostly made up of authors of a single school is the first one, which confirms its score being similar to the found scholastic stability (295 and 292). A discontinuist narrative that wants to abstracts away the productions of schools that still exist (although will not be central to the narrative) is misguided here. The further we get in time, the more schools co-exist, and the more schools co-exist, the lower general stability becomes. This drop in similarity could very well be due to an abundance of cross-school connections occurring in later slices of the corpus. And given that we also found out that Newtonians and scholastics are particularly conceptually dissimilar (a stability of 213), the persistence of scholastics into the eighteenth century could explain the disunity found across the century. Their dissimilarity from active Newtonians would reduce this period's stability.

However, before I can draw such firm a conclusion, I need to attend to a specific worry. Namely, what if there actually is a more productive way of splitting up the Latin corpus into three parts, just by laying down slightly different boundaries? Given that considering all options for splitting up the network is not humanly possible, I will employ a data-driven approach. Several methods are available, but not all of them are suitable, given the nature and constraints of my research.

There are several existing methods for temporal network clustering. However, I cannot use them here, because they define temporality in terms of changing edges (signifying changing relations between nodes). However, in my network it is the nodes (books) that are temporal whereas the edges (similarities) are not, making chronological clustering not applicable. Another method that could be applicable here is variability-based neighbor clustering (Gries and Hilpert 2008;2012). By asking which two temporally subsequent works are the most similar, the pair of works is collated into a single new work. This process is iterated until a desired number of slices is left. However, the disadvantage of this approach for my investigation is that by collating together different works into new works, the method disagrees with the decision to keep singular books as carriers of meaning. Additionally, since the topic of investigation is network stability, it is more useful to use stability as the variable that ought to be maximized.

Given that these approaches do not fit my corpus and network, I propose an alternative way to slice up the corpus. I allow an algorithm to consider every possible way to split up the corpus into three parts (using three-year periods). The proposed approach has the drawback that it is computationally expensive. Nonetheless, it guarantees that we see the single way to periodize the corpus into three parts that is on average most stable. The results of this process are listed in Table 2.10:

	Stability
Whole Latin corpus	266
1600-1652	290
1652-1720	268
1720-1800	269
Weighted period average	276

Table 2.10: Maximally stable subdivision into 3 periods (Latin).

The small difference between the maximal weighted average stability that is computationally derived (276) and the one found via top-down periodizing (272) alleviates the worry that there is a significantly more sensible way to locate the three periods. Additionally, the first period is very similar to the supposed scholastic period and has a similar stability (290 and 292). This indicates that scholastics dominate the corpus for the first 50 years and afterwards can expect opposition from subsequent schools. The two following periods do not map unto what we derived on the grounds of Descartes' and Newton's publication dates so neatly. Instead, they both signify that the increase in Cartesian and Newtonian production follows only sometime after their founder's publications, which is reasonable given that it takes time until the influence of a school becomes spread across the corpus to the extent that it impacts stability scores.

The low stability throughout the Latin corpus from 1644/1652 onwards suggests that conceptual change occurred and that multiple schools coexisted. Did that change and did coproduction continue indefinitely? The answer seems to be 'No', since we do know that *at some point* scholasticism and Cartesianism were properly played out within natural philosophy. This did not happen starting with the publication of Newton's *Principia Mathematica*. Perhaps the best would be to hypothesize a fourth period, one in which Cartesians and scholastics play lesser roles within the natural philosophical program. The hypothesis would be that this fourth period, consisting mostly of Newtonians, should be again more stable. Considering, for example, only the 1767-1800

period[23] in the corpus, I find a stability of 309 (the same as the Newtonian stability of 309). Such a division would result in a four-period chronology, for which the stabilities are given below:

Period	Stability
Whole corpus	266
1600 – 1644 (Scholastic period)	295
1644 – 1687 (Scholastic Cartesian debates)	272
1687 – 1767 (Scholastic, Cartesian, Newtonian debates)	266
1767 – 1800 (Newtonian period)	309
Weighted average of the periods	278

Table 2.11: Four-way division that includes a final period in which the stability markedly increases.

The division improves at least on the optimal 3-way split of the corpus average. This outcome roughly equates to the corpus consisting of two periods of relative conceptual stability: 1600-1644 and 1767-1800. The flipside is that the large century that lies in-between was actually relatively turbulent. Multiple different approaches to natural philosophy coexisted. Perhaps the schools were also still developing themselves. Anecdotally, early modern historians usually focus exactly on this unstable period and less on the periods surrounding it. This would make sense – when the history is itself conceptually unstable, there is more work to do for the historian of (natural) philosophy.

2.5: Discontinuity or Continuity? Descartes on 'Causa'

I take the results in section 2.3 to be clearly in favor of seeing these labels of scholastic, Cartesian and Newtonian, as informative and substantial labels. In this sense, there is a clear discontinuity in early modern natural philosophy: the constitution of new schools of natural philosophy severely impacted the conceptual profile of the discipline. But what, if anything, do the results tell us about recent attempts to focus attention on forms of continuity between different authors from different schools of philosophy?

Not as much as one might think. Regarding the Cartesians' reworking of causality, for instance, Nabeel Hamid succinctly shows how Cartesians narrowed down the scope of the meaning of causality:

[23] The choice for the year was so as to generate a highly stable final period.

> The early modern period witnessed a narrowing of the meaning of cause. Whereas the scholastic tradition had worked with a broad notion of cause as an explainer, inherited from Aristotle's multifaceted concept 'aitia/aition,' the mechanical philosophy sought to restrict it to that which explains in virtue of acting. (Hamid 2021, p.2)

The Aristotelian fourfold of causes (material, formal, efficient, final) get reworked by the Cartesian mechanicists by understanding causality mostly in terms of efficient causation. To a certain extent, there is truth to this reconceptualization and to the discontinuous view that results. Cartesians tend to reduce a broad conception of causality to a narrower conception (which we eventually inherited into our modern everyday usage). This is perhaps one of the many routes of explaining the higher semantic unity among Cartesians than between Cartesians and scholastics. At the same time, however, Descartes' indebtedness to late scholastics (like Francisco Suarez [1548 – 1617]) for his 'new' concept of causality has been brought out in recent scholarship (Des Chene 1996; Flage and Bonnen 1997; Schmaltz 2008; Hattab 2009). As Tad Schmaltz notes in his monograph detailing Descartes' views on causality, Descartes' innovations were prefigured by scholastic innovations:

> It is not too surprising that this shift to a focus on efficient causation has a history. What is perhaps surprising, though, is that the development of the Aristotelian theory of causation in early modern scholasticism prepared the way for the shift reflected in Descartes' writings. (Schmaltz 2008, p.4)

Later scholastics, like Suarez, paved the way for the move that Descartes would be making, including the restriction of causality to efficient causation, as others have also argued (Carraud 2002; Fink 2015). Schmaltz is, nevertheless, well aware of all the distinct ways in which Descartes does move away from his scholastic heritage (2008, p.44), and, in fact, he qualifies in what particular ways it is useful for him to focus on the context and similarities with scholasticism–they allow for filling in some of the blanks in Descartes' own writing: "What is new […is] to use our knowledge of scholastic treatments of causality as a key for deciphering Descartes' often-cryptic remarks […]." (2008, p.4)

One may conclude that two stories about Descartes' reworking of causality–one in terms of discontinuity (breaking with the Aristotelian fourfold of causes)[24] and another one in terms of continuity (the similarities with late scholastic interests in

[24] In the next chapter, we will see that 'causa' is one of the most unstable terms in the corpus, which gives further traction to the idea that something happened to the semantic contents of the term over the course of the period.

efficient causation as the paradigm case of causation)–are both viable forms of analysis depending on a researcher's interests. Whether or not we want to focus on the discontinuous or the continuous in our writings is a meta-level choice about what scholars are interested in seeing and emphasizing. The quantitative results in the previous sections cannot tell us that there is absolutely *no* continuity or similarity between two groups of works, or among works from these two different groups; it can only tell us where there is more or less continuity. Both analyses of Descartes' approach to 'causa' are historically valuable, and it is neither confirmed nor opposed by the knowledge that Cartesians are more internally similar than similar to scholastics. What this demonstrates is only that some extreme form of continuism is misguided: the school affiliations scholastic, Cartesian and Newtonian, do cut philosophical language at (or close to) its joints, and, as such, are historically helpful ways to conceptualize early modern natural thought. The three schools of natural philosophy are characterized all by their own semantic profiles that differentiate them from that of the other schools.

2.6: Conclusion

In this chapter, I have investigated the semantic stability of different terms, different schools and different periods in early modern natural philosophy. In general, the semantic unity of early modern natural philosophy seems to have been influenced significantly by school affiliation: either scholastic, Cartesian or Newtonian. These three historical labels, which were also labels used for self-identification, provide coherent conceptual frames for making sense of key terms in natural philosophy. Additionally, the connections among these three schools were not similar. Whereas Cartesians appear to be both somewhat proximate to scholastics and Newtonians, the conceptual similarity between Newtonians and scholastics was very low. This finding confirms the developmental story often given of the period: scholastics make way for Cartesians and Cartesians pave the way for Newtonians. However, by looking at various time slices of the corpus, I found a different picture. Scholastics, Cartesians and Newtonians presumably have a century during which they all make up a significant part of natural philosophy. Although eventually the Newtonians are the only ones left, and were the last to rise, this should not be confused with the idea that the schools simply replaced each other. Instead, the period between 1644 and 1770, appears to be the least stable and, thus, the most historically engaging part of the corpus.

The continuity of semantic development in early modern natural philosophy where schools work with their predecessors' conceptual frames, runs from scholastics to Cartesians to Newtonians, which allows for a continuist narrative. By contrast, the fact that these groups are substantially internally stable suggests a discontinuous

narrative, where the differences between these schools are more pronounced than their similarities. Both ways of looking at early modern development of philosophical language are valuable and useful. In Chapter 5, I will return to the question of "disruption", and try to tell a story of disruptive works within the corpus. But before continuing the analysis of disruption and influence of and between authors in Chapter 4 and 5, I want first to expand on the analysis of term stability executed in section 2.3.1 by expanding the conceptual granularity that stability can pick up on, to further our understanding of terminological stability in early modern philosophy.

3: Facets of Meaning and Functions of Words: Salience Differentiated Stability

> "[…T]hese essays see Kant as a problem solver whose favored instrument of work is the distinction. Whenever we look to Kant we find him preoccupied with what he sees as essential distinctions […] And all of these distinctions afford tools for addressing philosophical problems that must […] be resolved through the development of suitable conceptual and doctrinal instrumentalities."
>
> (Nicolas Rescher, *Kant and the reach of reason: Studies in Kant's theory of rational systematization* 1999, p.1)

3.1: Introduction

In section 2.3.1, I analyzed the stability of individual terms within the corpus. The results corroborated general intuitions: scholastic terminology is relatively unstable, whereas simpler terms, like 'sun', are quite stable. However, the amount of information I could extract about these individual terms was not overwhelming. Instead, stability has been leveraged to define stable groups of works as schools in the sections that followed. Some results (especially the high stability of terms like 'motion' and 'body', so central to the changes that Cartesians and Newtonians introduced during the period) were unexpected and in need of explanation. In this chapter, I expand on the analysis of the keywords themselves by extending the sensitivity of the stability analysis and allowing for more semantic variation in the analysis. English language terms will be classified based on multiple ways to account for their stability within a corpus of texts.[25] I will also focus on the analysis of the terms themselves before returning to authors and schools in the coming chapters. Whereas schools were found to be semantically discontinuous, this was only partially visible in the stability of individual terms. The more fine-grained analysis of individual terms will readily show the impact of schools on the development of terminology: terminological instability (of some kind) generally derives from the functions that words play within (or between) schools that use this terminology.

[25] This chapter is based on a previously published article (Hogenbirk and Mol 2022). Due to the state of the corpora during this stage of the research, I opted to use the English language terms instead of the Latin with which the other chapters deal.

To expand on stability analysis, I introduce a fourfold classification of words based on the idea that not all conceptual (dis)agreements are created equal. If authors within a corpus generally disagree on the very visible context of application of a term while agreeing on the less visible way of applying a term, one might expect the term to be a topic of much debate but, at the same time, to provide some grounding to a doctrinally fueled discussion. I call these *Integral Controversy Terms*. Vice versa, a term that appears to be used in similar ways but has subterraneous conceptual dissimilarities might be expected to be a term that hides real disagreement underneath *façade-like posturing.* The subterraneous conceptual dissimilarities will turn out to be prime candidates for further investigation with computational means.

In order to develop a novel measure that considers different kinds of conceptual (dis)similarity, I need to first make sense of a word having multiple ways to differ semantically from other words. If meaning is multifaceted, then different algorithms might extract different models of the word's meaning. In section 3.2, I draw on the work of philosophers like Mark Wilson and Sally Haslanger (2006; 2012) to argue that a word has salient, more publicly known and obvious semantic content as well as more subtle and, hence, less salient content. I will argue that both are important aspects of the semantics of a word.

Consider that in Chapter 1 I have argued that there is an interpretable operation that delineates a list-of-collocates model of a word's meaning from the full sparse vector model. In section 3.3, I argue that the difference between the sparse vector model and the collocate based model is exactly one of salience. The restricted-list method, which extracts a list of strongly related terms, tracks the salient connotations whereas the unrestricted method (unchanged sparse vectors) tracks its more complete use, including hidden semantic subtleties. In section 3.4, I combine these two different approaches with conceptual similarity. Words will be classified based on the difference between the stability scores found using sparse vectors and collocate lists. I dub this Salience Differentiated Stability (SDS), which is a two-vector signifying a word's relative salient and less salient stability. This is a metric that will be applicable to any given corpus of texts, for any word in the corpus. I argue that the four types defined by the two-vector map unto four different classifications of the role a term plays in the unification of natural philosophical discourse. These are 1. particularly stable in salient aspects and non-salient aspects; 2. particularly saliently stable but non-saliently unstable; 3. particularly saliently unstable but non-saliently stable and 4. particularly unstable in both their salient and non-salient aspects. These four cases will all be given a particular interpretation.

In section 3.5, I provide the results of a case study where the Salience Differentiated Stability of a subset of the English language corpus for a set of word-types is extracted. I find that the method both agrees with historical literature and provides non-trivial results. They could have been trivial if the varying salience yielded no difference in results or none that could be plausibly interpreted. Words which score high for salient stability do not necessarily score high for subtle/less salient stability, nor vice versa. This means that in actual historical examples, salient and less salient semantic content can be quite different both in content and in overall stability. It turns out that 'body' and 'motion', terms that were unexpectedly stable in Chapter 2, are *integral controversy terms*, that is, words that are stable only in the underlying usage of the term but otherwise very openly unstable.

Finally, in section 3.6, I explore words discussed in the literature about the history of early modern natural philosophy. It turns out that commentators' focus has been on words that are among the saliently instable terms (*Integral Controversy Terms* and *Crisis Terms)*.

3.2: Salience and Semantic Pluralism

Begriffsgeschichte argues that terms alter their meanings and that this is partly because there is a certain implication of continuity in the use of the same term. Using the same word in different contexts and across different times forces an actor to relate to the meanings attached to the word in earlier times. This is a diachronic account of the ways the same term might differ in its meaning. I have expanded on this account by making the same term differ in meaning across its published contexts, generating an idiosyncratic meaning attached to word for singular works of natural philosophy. However, for all this differentiation in contexts and meanings, this approach still assumes that different works can only (dis)agree with the meaning attached to a term in one single way, which can then be measured.

Let us now recall from Chapter 1 that in the sparse vector approach a word is characterized as a large vector. Within this vector, each of the coordinates signifies how often another word-type appears in close proximity to the word this vector is a model of, with a large number signifying a high score. For a list of collocates, one extracts those entries from the vector that meet a score threshold. These are two different ways of extracting semantic models of words in a text. In the first case, the model is the whole vector. In the second, it is the whole list of terms that are extracted. Confronted with such a plurality of models and working on the assumption of the unicity of meaning, one may wonder which one is the better choice. I could argue that either one or the other

model more accurately shows the meaning of the terms they model. Either the meaning of a word is mostly determined by the words it is associated with the most (collocates), or alternatively, by the way it is associated with all other word-types in the text (sparse vector). This dichotomy, however, constitutes a false dilemma. In this section, I will argue that there are different ways to conceive of the semantic content of a word. And given that there are different semantic contents, I will afterwards argue that different algorithms and models might be targeting these different semantic facets.

In order to move to, and qualify a specific sort of, semantic pluralism, I introduce examples of semantic pluralism from philosophers of language. Sally Haslanger (2012) has argued that one may apply different forms of analysis to terms in order to extract different meanings that the terms carry at a single moment. I focus on two kinds of analysis: a conceptual analysis and a descriptive analysis of a term. A conceptual analysis is well known to the philosophical community; by formulating necessary and sufficient conditions, considering imagined examples and other explicit tests, a conceptual analysis can bring out the salient, explicit, definitional meaning of a term. By contrast, a descriptive analysis might disagree with the meaning one would extract from merely thinking about the definitional nature of the term. This is done by taking into account the concrete practices that surround the term. Haslanger provides the example of tardiness at her son's primary school. Definitionally, a child is tardy when they arrive after 8:25 AM; however, Haslanger's son pointed out that this definition did not map unto the actual practice of tardiness: "Don't worry Mom, no one is ever tardy on Wednesdays because my teacher doesn't turn in the attendance sheet on Wednesday until after the first period." (Haslanger 2012, p.268) What it means to be tardy here diverges between the two different ways of analysis. An analysis of explicit definitions (i.e., the manifest meaning) of 'tardy' would imply a child to be tardy when arriving at 8:26 AM on a Wednesday. Yet, the operative definition, that takes into account the practice of taking attendance would suggest that this same child is not tardy. The point is not that the one or the other facet of meaning is the correct one, the point is that both facets of meaning are doing work that is relevant to the analysis of language. This also means that either one of these methods for the analysis of meaning is going to be one-sided. Merely thinking about tardiness and asking the school administration about 'what tardiness means,' would provide a limited view on what the term actually means. This also implies that parts of the non-explicit meaning can be hidden from sight since it requires a form of analysis that is not immediately open to a user of the term (a descriptive analysis needs at least a somewhat extensive amount of time and energy in order to be executed).

Wilson (2006) similarly differentiates between elements of meaning that are easily accessible and open to anyone and elements of meaning that are difficult to

retrieve. He introduces the concept of a 'façade': a term that at first look appears to be simple in its attached meaning, but in reality changes in meaning in subtle ways across contexts (Wilson 2006, p.147). These differences are generally hard to see. At the same time, the implied continuity by using the same term exacerbates the difficulty in extracting the terms' differing uses.

Wilson uses the example of hardness to illustrate a façade term. One the one hand, we have an immediate idea of what it means for a material to be hard. Yet, whenever an investigator applies pressure to extract a clear meaning they are frustrated in their attempts. For, upon the inspection of practices in which hardness is used to deal with the world (steel factories wanting to have 'hard' steel, or glass factories wanting to produce properly 'hard' glass), it turns out that the definition of hardness drastically differs according to the specific material. Whereas resistance to indentation is the way to identify a 'hard' metal, resistance to scratching in the meantime is the way to specify a 'hard' sheet of glass. Whenever we pressure our understanding of concepts, some of them turn out to contain a lot more ambiguity than we are generally inclined to think they have. Sometimes it turns out there is a way to get terms that nicely map unto reality and not become façades. Wilson's example is the modern understanding of temperature, where different measures of temperature can be safely understood in terms of degrees of Kelvin: a measure of temperature that has claim to allowing any other system of measurement to be mapped unto itself. However, hardness resists such a treatment. The meaning of hardness is multifaceted despite our intuitions that it ought to be univocal.

Haslanger and Wilson agree that the meaning of a term is not exhausted by the salient, explicit and easily accessible meaning. Instead, many terms (although not all) manifest divergence between the use of the term and the stated meaning we ourselves would give to the term. Both of these facets of meaning are of interest for someone investigating the vocabulary of some group of language users. To distinguish between these two facets of meaning, I make use of the concept of salience. The more salient aspects of meaning are those easily accessible, definitional and explicit. The less salient aspects of meaning are those which are less easily accessible, operative and hidden. I will argue that two different methods for meaning extraction map unto the aspects of meaning that are more and less salient.

3.3: The More and the Less Salient

The two methods for the extraction of semantic information about word-types from a corpus are: (1) extraction of lists of collocates, and (2) generation of a vector-

representation. In Chapter 1, I argued that the difference between these two models can be understood through the operation that is needed to translate between the two representations. Let us assume we have some sparse vector representation of the use of a word in a text or corpus. The individual entries within the vector signify the 'strength' of their connection through the Pointwise Mutual Information (PMI) measure, or some other measure that turns collocation counts into scores signifying connective strength. The higher this score, the more the two words occur in each other's proximity. Such a singular score might then be taken to signal the association between these words in the inspected text.

Meanwhile, for collocate extraction, one extracts those terms which have a particularly high score within the vector. That is to say, using collocate extraction, we get a list of words that have a particularly strong association with the word that is investigated, whereas within the vector we are dealing with connections of differing levels of strength. These more extreme coordinates in the vectors, I propose, are the more salient connections that term has, since they are defined by a strong association. By contrast, the whole of the vector contains also connections that are defined by a weaker association, yet they have a reality in the written texts; these, I suggest, make up the more subtle semantic facets of the term.

Is there any reason to assume that high pairwise PMI scores between terms correlate with associability and would lead to statements of recognition by readers of a corpus in which the words are thus correlated? Some psychological research suggests as much. Pairs of words that have higher PMI scores are for example judged to be similar by test-subjects (McDonald 2000, p.35-67). When not judged as themselves similar, the words are also judged to be significantly related in terms of meaning (McDonald and Ramscar 2001). PMI thus tracks textual properties that have psychological ramifications for readers of these texts and high scores additionally suggest the salience of the connection between the terms for a reader of texts in which these textual properties occur. This is an argument in favor of reading collocate lists as signifying saliently connected words.

The argument in favor of reading the lower scores as non-salient connections is, however, circumstantial. But this is necessary, since non-salient aspects of meaning or association cannot be easily extracted via the explicit questioning of test-subjects. In these cases, the subjects themselves would have a hard time explicating their subterraneous semantic behaviors. In section 3.5, the results show that, in at least some cases, looking at the high scoring words only yields different results from looking at all word associations, and that this can be reasonably interpreted. And, in section 3.6, I argue that the discrepancy between the results obtained using salient measures and

non-salient measures is to be expected given that it is harder to recognize subtle-meaning properties by personal textual investigation.

3.4: Salience Differentiated Stability and a Typology of Terms

Given two different measures to extract meaning and their attached similarity measures, each mapping unto a particular facet of meaning, it is possible to expand measures to incorporate these different facets of meaning. The difference in outcome using different basic meaning extracting algorithms can then be compared.

In Chapter 1, I introduced stability; a measure of the average pairwise similarity of a term within a corpus of texts. A high stability suggests a term that is broadly (within that corpus) used in the same way, whereas a low stability suggests that the term has a less agreed upon conceptual content. In the same chapter, I also implicitly used the sparse vectors to extract meaning. This also means that what has been extracted in Chapter 1 is the stability of exactly the non-salient facets of the terms' meanings. Alternatively, I could also have extracted the stability of a term using the collocate-based model of the term's meaning. This stability would signify then the stability of the salient facets of the meaning of that term, not its subtle facets' stability. Besides the possibility of choosing between different stability measures depending on the application, what I will introduce here is a measure that combines these two different scores and interprets their difference: salience differentiated stability.

In the approach I am proposing in the current chapter, a single word will be given two scores: the stability of the salient facets of meaning of a word in a corpus *and* the stability of the subtle facets of meaning of that same word in the same corpus. These two scores can be relatively saliently (un)stable (above/below average salient stability) and relatively subtly (un)stable (above/below average subtle stability). The values can be expressed in terms of the percentual difference from the average. A salient stability score of 120 signifies that the term is 20 percent more saliently stable than average, a salient stability score of 80 signifies that the term is 20 percent less stable than average. This means that the values for salient and subtle facets of meaning are mapped on comparable values; a salient stability of 120 and a subtle stability of 120 both signify a similarly above average stable term.

In this way, I am able to generate a typology of words in terms of the relative values of their two sorts of stability. That is to say, if salient stability can be both high and low, and subtle stability can be both high and low, four categories present themselves for classification: saliently stable and subtly stable terms (high, high), saliently unstable and subtly unstable terms (low, low), saliently stable but subtly

unstable terms (high, low) and saliently unstable and subtly stable terms (low, high). These categories can be visualized using four quadrants set up by two axes on a two-dimensional plane, and plotting every term on these axes in order to see where in the quadrant they fall. Each of these quadrants also suggests a typology for the terms that fall in them:

Simple Terms: Terms that are generally stable (both subtly and saliently) are terms used in similar ways across all authors in a corpus. Given that the terms have been extracted using topic modelling, their agreement does not derive from a lack of interest in the term, but in a certain simplicity in the use of the term. This means they might be topics of investigation where what is at stake is not so much a (dis)agreement about what the thing really is, or what examples of these things are, but only what specific behaviors or properties might be attributed to them.

Integral Controversy Terms: Terms that have a lot of salient dissimilarity but that are used in subtly similar ways are terms that are visibly and explicitly being renewed across authors despite there remaining a certain hidden conceptual agreement. The upshot of such terms is that their underlying conceptual agreement (subtle stability) might allow for fruitful doctrinal (explicit and salient) disagreements.

Façade Terms: Terms that have a lot of salient similarity but that are subtly unstable are terms that people might take themselves to agree on amongst themselves despite all kinds of hidden ways in which the terms' usage conceptually diverges. I make use of Wilson's name 'façade' for this because, like with 'hardness' what at surface level appears to be a simple term, hides all kinds of applicatory ambiguities.

Crisis Terms: Terms that are generally unstable (both subtly and saliently) are terms that are used dissimilarly across authors in the corpus. Potentially, these terms are at the center of controversy between thinkers, who are competing in a tug-of-war for the conceptual contents of the term. However, being central to a controversy doesn't mean that the term is helpful – a crisis term also signifies a lot of people 'talking past each other'. We might be missing out on the meaning another is attaching to the term, and we might even disagree at some point, about what examples of these terms are supposed to be.

3.5: Early Modern Natural Philosophical Terminology

If the case study were to bear out that all words are similarly stable, or that Jaccard scores do not yield different results from cosine similarities, the method would be trivial. If some of the results were not plausibly interpretable, the results would simply be too garbled to show anything meaningful. Neither appears to be the case.

The corpus used in this investigation consists of fifty works from the English language primary corpus. At the time of the experiment, this was the complete digitized primary English language corpus available in the project. The eventual English language corpus would end up significantly larger. However, this experiment was made early in the research cycle and has been published; as such, I have opted to use the results derived from this smaller subcorpus instead of rerunning the experiment with the entire English language corpus.[26] The selection of texts can be found in Addendum 2. Note that this sub-corpus has been built up without preference to particular philosophical schools, and contains a spectrum of natural philosophical schools and their works.

Similarly, as with the corpus construction, the parameters used in the tuning of the algorithm are slightly different from those found throughout the rest of the dissertation. This experiment sees the low frequency words (<4) removed, numbers, interpunction and singular letters removed, as well as decapitalization of all the words. It also sees noisy word-types due to OCR and articles removed. These steps are particular to this case-study, but the SDS-scores do not depend on any of these steps and can be applied to raw-texts as well as more heavily cleaned texts. On the grounds of this corpus, I modeled fifteen key terms' SDS-scores, extracted via topic modelling, executed in an early stage of the research project.[27]

In Figure 3.1, you can find the SDS-scores of these fifteen terms. The terms will be classified by the system introduced in section 3.4.

[26] Given that these subcorpus is a more or less random selection from the whole eventual English corpus, and that stability is an aggregate averaging measure, the expectation is that the results we would get from the whole corpus would not be very different. This is partially supported by a recent application of the method on the whole English corpus (Sangiacomo & Hogenbirk, forthcoming) where some of the words were scored again ('body', 'matter' and 'motion') and these terms were scored quite close to their places on the current graph.

[27] Due to the earlier execution, the list of terms is slightly shorter than and different from the selection of terms used in the other chapters: 'body', 'motion', 'matter', 'part', 'cause', 'form', 'specie', 'experiment', 'fire', 'electricity', 'method', 'earth', 'water', 'sun' and 'object'.

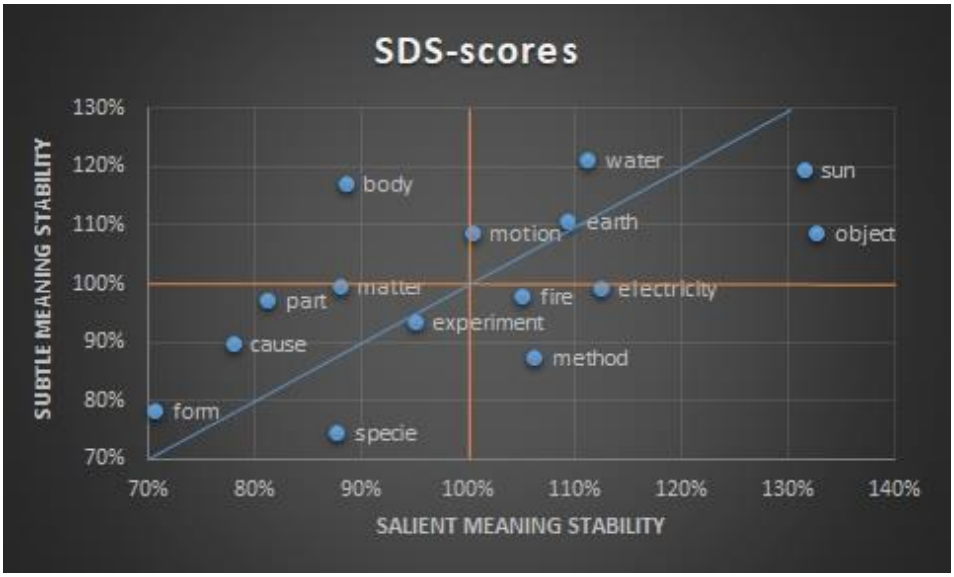

Figure 3.1: Positions of terms based on more and less salient stability scores.

This is a plot of the terminology scores. The horizontal axis shows the average similarity normalized to the average corpus-wide similarity scores based on the collocation-based approach; the vertical shows the same for the vector-based approach. Four quadrants can thus be derived, on which the values are plotted; they agree with the four categories introduced in the previous section.

The lower left quadrant contains terms with neither salient nor subtle stability, the terms provoke discussion and their legitimacy is opposed. The upper right quadrant displays terms that exhibit stability both in salient and subtle facets of their meaning (i.e., unproblematic, generally simple terms). The lower right quadrant signifies terms that exhibit façade like behavior: the terms are stable and unproblematic at the surface level but, at the operative level, exhibit unrecognized semantic shifts. Finally, the top left quadrant shows what I have dubbed integral controversy terms: despite being central to much discussion, the terms exert a unifying power on the discourse through their subtle similarity.

3.5.1: Simple Terms

In the upper right quadrant, there are four terms (excluding 'motion'): 'earth', 'water', 'sun' and 'object'. The commonality of the first three terms is that they all refer to identifiable, concrete, things. This is, of course, not to say there were no interesting discussions about these terms (a lot of astronomical work was done on the relation

between the earth and the sun, and on the nature of these two planets) but the terms are still relatively straightforward in terms of meaning. For 'sun', in particular a simple ostensive definition is available, somewhat similarly for 'water' (water being this ostensively available stuff, and other similar stuff). Indeed, the three terms are all very neatly counted as easily identifiable, concrete, objects of investigation within natural philosophy ('fire' and 'electricity' also appear close to this quadrant). 'Object' is the only abstract term of the four and scores somewhat closer to the façade quadrant than the rest. But, the usage of a term like 'object' is simple. Because even when speaking of mental, biological or physical objects, in all cases nothing changes about the ways in which they are objects.

3.5.2: Integral Controversy Terms

There are three words that fall (or almost fall) in the upper left quadrant that I have proposed to understand as being comprised of terms that are extremely central to the discourse and to much controversy but enforce a certain unity in the discourse via implicit agreement on the more general connections that such terms have. 'Motion' and 'matter' are edge cases, so let's first look at the clearest case, 'body'.

'Body' is extremely central to early modern natural philosophy. Early Cartesians let themselves be summarized in the striking sentence *bodies in motion*, or, *matter in motion* (Nadler 1993, p.3; Roux 2017, p.27-28). Although many schools (already existing in the form of scholastic schools, or later schools, such as Newtonians) will reject the mechanicist claim that the investigation of *bodies in motion* exhausts the activities of the natural philosopher, they however would all have to concede that mechanicism set the program: to be a natural philosopher is to (at least) have answers to questions pertaining to bodies (whatever they might exactly be) and their movements (whatever that might end up meaning exactly).

Once this program was set, it is natural that 'body' itself becomes a contested term. The philosopher who can provide and defend a conception of 'body' such that it easily fits with his/her more general outlook is a philosopher who has successfully scaled the walls of natural philosophy. At the same time, these moves need to be made out in the open since the eyes of the reader are fixed on these terms. Façade-like behavior is not to be expected: the entire disagreement is out in the open, and there is no manifest agreement that could help hide subterranean disagreement.

A few examples will show the extent of the mutability of 'body' within early modern philosophy, where these mutations are central to the arguments provided. Descartes' mechanicism comes together with a very explicit statement about the nature

of what bodies are: they are primarily characterized by their extension. This is coupled with a statement about the other 'type of thing' there is in the world, namely, thought. Bodies being extension means that all the other properties of bodies can be explained reductively by reference to their extensional properties (and their motions). If body is anything, it is to be extension, and if body is to not be anything in particular, it is not to be thought.

Amazingly, in opposition to this, later natural philosophers remain true to Descartes' style of reasoning about body (1. Body is central to their activity as natural philosophers and 2. It is an investigation into body's essential attributes and motions that should occupy them in particular) while, in the meantime, moving away wholly from his conception of body. Indeed, to make room for their particular systems of natural philosophy, thinkers like More, Cavendish and Conway more or less remove all properties ascribed to bodies by Descartes. For Conway, both the impenetrability (one of the ways the space filling 'extension' was often fleshed out) of bodies is opposed and it is claimed that bodies are both spiritual and material-like (Lopston 1982, p.15). Cavendish phrases the issue somewhat differently but, for her too, bodies are coupled together with mental properties (Shaheen 2019, p.3553-3554), as is the case for More, who arguably provides less reworking since he mostly takes the extended conception of motion to be incomplete in accounting for phenomena (Roux 2017, p.27). What allows for these very deep metaphysical discussions is that, in the end, bodies can be somewhat easily identified in everyday activity. And whatever the exact nature of bodies turns out to be, it should in the end still be mapped on a set of paradigmatic instances of bodies (even the radical turnaround one finds in a thinker like Conway, where one would expect the concept to be so definitively deformed to no longer map unto the same objects as previous concepts of body, is still applied to recognizable cases, like the different unmixed fluids and how they hang together in a single bottle).[28]

What about 'motion' and 'matter'? Generally, 'matter' was used more restrictively than 'body' – and was less easily identified with everyday objects in the way that bodies could be. One would expect that 'matter' was less stable in application because it was not so strictly tied together to phenomenally accessible paradigmatic examples ('bodies' might be best imagined as spheres, houses, coherent swathes of fluid, cannon balls whilst 'matter' was often understood to encompass more restrictively the corpuscles that make up bodies). This is due to the Aristotelian roots of the concept:

[28] She argues that a phenomenon like the freezing of a bottle of liquor producing a small unfrozen part with a higher density of alcohol (or, tentatively, spirit) can best be modeled as a separation of gross 'body' from the more supple 'spiritual' body (i.e., the unmixing of a liquid through freezing is a separation of the more spiritual bodies from the more matter-like ones). (Conway 1996, p. 43-44)

'matter' plays a role in the hylomorphic theories where things are essentially made up out of the combination of matter and form (Manning 2012).

Motion gets reinterpreted radically within early modern philosophy; motion as change makes place for motion as mere local-motion. However, this move is not as extensively challenged in the development of early modern natural philosophy as 'body' was. While 'body' functioned as the pivotal point where different conceptualizations could be made to do all of the metaphysical lifting, 'motion' did not take up such a place. 'Motion' was on the agenda but was more easily understood and less prone to the radical reinterpretations (after the initial reconfiguration) than occurred for 'body'.

These results allow for further interpretation in relation to the (implicitly) subtle stability scores in section 2.3, because one would expect that terms that are so central to the ideas of new schools of philosophy to be relatively instable terms. Yet, the words in the integral controversy quadrant are relatively stable with regard to the subtle facets of meaning. This meant that terms like 'body' and 'motion' appeared to be stable, despite their centrality to school development. Now we have seen that these terms are actually unstable with regard to their salient facets. These terms were central to the rise of new schools and therefore hotly debated internally by these schools. But, clarity of extension and lack of interest from earlier (dissimilar) scholastic authors allowed these terms to retain their subtle meaning stability and homogeneity.

3.5.3: Façade Terms

In the lower right quadrant, one would expect to find terms that exhibit façade like behavior. These are words similar in salient ways but dissimilar in more subtle ways. Superficial similarity may mask slippery differences in usage. Three terms seem to qualify – 'fire', 'electricity', and 'method'. I will not discuss 'fire', because, as we can see in the plot, the distance between 'fire' and the 'x=x line' is very small. That is to say, the difference between the more and less salient scores is very small (98/104).

Similarly, 'electricity' is quite close on the line toward the upper right quadrant. This means that the salient stability is pronounced, but the subtle instability (which places it in the façade quadrant) is not so high. This means that electricity's placement as a façade is not secure. One reason to expect 'electricity' to be close to the simple terms is that it has properties in common with 'earth', 'sun' and 'water,' in the sense that electricity designates a somewhat properly delineated group of phenomena. In particular, static electrical effects (which resulted in the attraction of other objects) and magnetic materials (which show somewhat similar behavior) were termed electrical. Additionally, the experimental context in which electricity is mostly discussed within this

corpus, combined with a prevalence of a few particularly influential experimental results (like, for example, the Leiden Jar), further substantiate that a certain terminological stability can be expected (Sangiacomo and Tanasescu, forthcoming). However, further study revealed that some previously 'electrical' phenomena should be delineated from 'the electrical *per se*', in particular excluding magnetic phenomena from the term's extension (Gregory 2007, p.35-42).

In addition, there is the novelty of the topic in natural philosophy as a systematic topic of interest: whereas it was of fringe importance in foregoing natural philosophy, it gets conceptualized more systematically within early modern natural philosophy; its novelty should make us expect less stability in the application of the term in its non-salient features, whereas identifiable phenomena should make us expect more stable non-salient applications. What is less easily explained is the cause for the agreement about salient facets of electricity's meaning, especially since the debate about electricity is often characterized as a number of schools disagreeing fundamentally about the nature of electricity (Gregory 2007, p.35-42). However, the agreement about the experimental context (and the general importance of experiments in the discussion of electricity) can explain the salient stability of the term. The most important context in which to discuss electricity (the experimental context) is, thus, what constitutes the salient content of the term, and this content is relatively stable. As electrical philosopher John Adams (1750 – 1795) notes in his *An Essay on Electricity*:

> As electricity is in its infancy, when considered as a science, its definitions and axioms cannot be stated with geometric accuracy. [… I] invite the reader to examine the experiments himself […]; beginning with those experiments which were the foundation of the present states of electricity, and which gave rise to the principal technical terms made use of in this science (Adams 1799, p.33).

Adams nicely formulates, I suggest, the reasons for why we find electricity (barely) within the façade quadrant. Firstly, salient stability is derived from the experimental context, which is generally agreed upon and which provides 'the principal technical terms' for the discussion of electricity. At the same time, electricity is a novel enterprise, leading to less subtle stability. This behavior does not exactly constitute façade behavior (due to the high subtle stability score). However, the conceptual agreement on the experimental context of electricity, might belie deeper disagreements due to the novelty of the discussion of the phenomenon and can be understood as weak façade behavior.

Central in the lower right quadrant is 'method'. Many early modern thinkers agreed on the centrality of method in science. Presumably, its salient stability can be explained by this agreement as well as by a shared understanding of the overall concept. One might be able to explain its subtle instability by the fact that method as a word

generally signifies that some technicalities are to come, but which technicalities, differs depending on which method in particular will be discussed.

If I am correct, the presence of 'method' in this quadrant can be explained without calling it a façade. Electricity is only somewhat façade-like: a conceptual agreement on the experimental context in which to discuss electricity belies the instability due to the novelty of theorizing about electrical phenomena. This means that the case-study did not exactly bear out my expectations – no very clear cases of facades were found in the lower right quadrant. Yet, difficulty in the interpretation of façade-like behavior should perhaps be expected – it is the one case where the instability that needs to be explained is fully hidden from view underneath salient agreement.

3.5.4: Crisis Terms

The most densely populated quadrant is that of the crisis terms (five terms, excluding 'matter') – 'part', 'cause', 'specie', 'form', 'experiment'. These are words which are understood differently and used differently. These terms are, thus, such that one should expect both that the terms were controversial and discussed explicitly in natural philosophy and that there were little methods available to tie these terms together via, for example, implicit agreement on the (paradigmatic) extension of these terms (as in the case of 'body').

All of these terms agree with this characterization. The four terms 'part', 'cause', 'specie' and 'form' are all derived from scholastic philosophy and heavily debated in early modern natural philosophy. Species, (substantial) forms and causes were all important aspects of the scholastic/Aristotelian framework, and were all reworked, or even outright rejected, in subsequent schools of natural philosophy like Cartesianism and Newtonianism (Blair 2006, p.366). 'Cause' is already reworked by Descartes, who also rejects (although not fully) substantial forms (Flage and Bonnen 1997, p.845). 'Species' is rejected by mechanicists as well. 'Cause' is outright rejected as being the proper object of investigation for natural philosophy by later Newtonians like van Musschenbroek (Sangiacomo 2018, p.51). Forms are sometimes reintroduced and reworked and all the while remain at play in the strong scholastic school that remains in operation for most of the early-modern period, particularly in the university context (Sangiacomo *et al.* 2022b). What differentiates these terms from 'body' are two things: 1. 'body' has easily accessible paradigmatic instances of the concept's extension which are not so readily available for, for example, part and form (and arguably, at least some of the fourfold of Aristotelian causes); and 2. whereas 'body' was extensively discussed in the light of its given central position to the new schools of natural philosophy, these

terms were discussed because their position within natural philosophy was under dispute as they were transported from one school to the next.

'Experiment' has a similar structure, except there the discussion will not have been most explicitly between scholastic and new philosophies, but between rationalist/Hobbesian conceptions of natural philosophy and experimental or Boylean (Shapin and Schaffer 1985/2011). Not only is 'experiment' a more technical term that allows for less easy identification of its extension (what even counts as an experiment, as opposed to observation, or an uninformative 'account') but also, in these debates, it is still up for grabs whether it has any place in natural philosophy. In this sense, I claim the terms in this quadrant to be crisis terms: they are central to natural philosophy, because in many ways, the form of the discipline is transformed by drastically questioning the contents and validity of these terms; however, these terms' total instability derives from the disagreement across schools about their conceptual contents. Meanwhile, integral controversy terms are central to the development of new schools of philosophy, allowing for significant disagreement between thinkers with regard to these terms, without losing a general way of speaking that allows for subtle meaning stability. School formation and author clusters are thus central to individual terms' salient differentiated stability, as it is within these contexts (or in the case of crisis terms, across these contexts) that much of their semantic behavior and function is fixed.

3.6: Conclusion: (Computational) History of Philosophy – a Salient Bias?

In this chapter, I have introduced and applied the measure of salience differentiated stability (SDS) on a small subcorpus of the English language 1600-1800 corpus. I have argued that, using SDS, we can extract different kinds of terms based on their relative salient and non-salient stability scores. The terms themselves were interpreted and placed within this conceptual frame.

Besides the analyses of the individual terms, what do we see emerging in the broader outlook on the development of thought in early modern philosophy? For one, it suggests that schools are an important causal factor in how the semantic behavior of terms shows itself in terms of stability. Nevertheless, a second observation concerns the way that the quadrants overlap with general historical interests about the period. Intuitively, the history of philosophy has been occupied mostly with words on the left of the scatterplot. That is to say, I am inclined to say that the words with low salient stability have been of particular interest. Moreover, words on the lower side of the scatterplot might indicate more historical interest as well, although the picture is significantly less

clear. It is *prima facie* sensible that contemporary scholarship should focus on terms that have lower semantic stability, as there is more to disentangle in these historical debates. The stable terms should be expected to be of lesser interest, as here less historical work is required.

In order to give weight to these observations, I use a rough indicator of a term's importance in the scholarship. Using OCRed versions of 1,800 articles from the history of science journal *Isis*, I find the raw word-counts of the fifteen terms discussed above, the idea being that words that are generally of historical interest will pop up more in historical journals. The reason for using *Isis* is pragmatic in nature: OCRed version of these articles were already internally available. This indicator is thus limited by the fact that, on the one hand, it does not only concern our period but also the later and earlier ones and, on the other hand, it focuses on the history of science only, and not on the history of philosophy. In addition, no attempt is made to disambiguate historical use of the terms from contemporary uses ("Newton did an *experiment*" vs. "I did an *experiment* using word-counts"). However, in Table 3.1 below we can see that the results do speak toward the general interest in saliently unstable terms:

1.part	**2.motion**	**3.form**	**4.matter**	**5.body**	**6.earth**	**7.species**	**8.method**
9566	6356	5954	5914	5741	5516	4645	4411
9.experiment	**10.sun**	**11.water**	**12.cause**	**13.object**	**14.electricity**	**15.fire**	
4164	3660	3421	2595	1931	1534	1409	

Table 3.1: Word counts in 1800 Isis articles of 15 key terms.

The average occurrences of these words in 1,800 *Isis* articles is 4,434. So, how do the saliently stable words stack up against the saliently unstable ones and how do the subtly stable words stack up against the subtly unstable:

Saliently stable terms	**Saliently unstable terms**	**Subtly stable terms**	**Subtly unstable terms**	**Average stability**
3491	5511	4387	4465	4434
motion, earth, method, sun, water, object, electricity, fire	body, matter, experiment, part, cause, form, specie	body, motion, earth, water, sun, object	part, form, matter, species, method, experiment, cause, electricity, fire	All terms

Table 3.2: Average wordcounts per side of the scatterplot.

The first thing to note is that when comparing the top half (subtly stable) with the bottom half (subtly unstable) of the plot, we find hardly any difference in the number of

occurrences (4,387 vs. 4,465) of the words (as they were found in *Isis)*. However, when moving from the left (saliently unstable) to the right (saliently stable) we find a quite big difference in average times the term occurred in the same publication (5,511 vs. 3,491).

Although this is a rather explorative claim that would need a more substantial database to be argued for, it seems that historical scholarly interest mostly maps unto the measure of saliently unstable terms. And it would make sense that this groups of terms would incur the most interest. Firstly, the unstable terms will usually play a central role in the debates that are being investigated and traced. Stable terms will not be the topic of prolonged investigation if only because their meaning is so 'simple' that at some point further disentanglement in the historical analysis is no longer necessary. Secondly, salient instability will be, by its very nature, easier to spot when reading through the original texts. Usually, the authors will themselves highlight their disagreements with other with regard to these terms. If not qua meaning, then at least doctrinally. And not only that, the instability can be analyzed quite readily using close reading. This is because the conceptual disagreement can be expected to be a theme within the debates themselves and thus allow for investigation via prolonged investigation of these debates. So, if we return to the scatterplot, we might expect that the words on the left can be analyzed quite well using classical methods. The conceptual instability (which is of such interest) will be visible and most likely thematized.

Meanwhile, on the right side of the plot, the upper right quadrant remains relatively uninteresting; words that bear no instability might be less interesting to scholars, and rightfully so. However, it suggests that what is less easy to investigate by close reading and yet potentially interesting (due to there being instability to disentangle) is the lower right quadrant. In the above discussion of the terms in this quadrant, it was already clear that these proved harder to place and explain than those in the other three categories. If so, and if correct in assuming that close-reading will be picking up on the instability to a lesser extent than in the case of its salient cousin, it is on this category that further development of measures and interests should focus within computational history. It seems to me that the way forward in the analysis of the development of early modern terminology is through the analysis of terms that belie their instability, that hide their differences and that do not thematize their fractured nature; however, this is not the route taken further in this dissertation.

In the coming chapters I return to using the vector approach to meaning modelling in order to expand the discussion about relations of influence that run between authors. In Chapter 4, we will see that this approach allows for the reversal of explicit doctrinal avowals of dissimilarity in the case of Anne Conway.

4: Conway in *n* Dimensions
Semantic Similarity as Potential Influence Relation

> "From what has just been said, and for various reasons offered that spirit and body were originally one and the same in the first substance, it plainly appears that the so-called philosophers who have taught otherwise, both ancient and modern, have generally erred and laid a poor foundation from the beginning; [… So] let no one object that this philosophy is nothing but Cartesianism or Hobbesianism in a new guise."
>
> (Anne Conway, *The Principles of the Most Ancient and Modern Philosophy* 1996, Chap IX, p.63)

4.1: Introduction

In Chapter 2, I have shown that different schools of philosophy carry increased conceptual similarities among their members for key terms. This was tested using semantic similarity scores. I considered groups of authors, and interpreted their general similarity as conceptual stability. In Chapter 3, I argued that such semantic similarities will unveil subtle facets of meaning. However, this does not provide an interpretation of the individual similarity scores between specific pairs of authors. Admittedly, it is important for ideas and concepts to be generally agreed upon in the intellectual climate in which one works. Nevertheless, equally ,often authors learn from other specific authors. This raises the question of whether we can interpret pairwise semantic similarity as an indicator of a relation of *influence* running between individual authors.

In this chapter, I will argue that semantic similarity is an indicator of a relation of influence, both conceptually and via a case study which shows that this interpretation of the scores can provide historically helpful results. To build my case study, I trace the influence of *mechanicism* as it runs from authors like Descartes and Hobbes to Anne Conway (1631-1679). Given that we have found that Cartesians formed a coherently stable group, one would also expect that Cartesianism is semantically impactful outside its narrow confines. Conway is a useful case due to the troubled history of her (scarce) works. I will argue that Cartesianism is indeed, despite the doctrinal disagreement with Conway, the most central source for Conway's work. In Chapter 5, this approach will be

generalized to investigate the corpus as a whole again, extracting features of semantic strategies of schools, as members influence each other internal to each individual school.

Conway was a seventeenth-century philosopher whose remaining corpus consists in a number of letters[29] and a singular work of philosophy: *The Principles of the Most Ancient and Modern Philosophy*, originally published in 1690 (hereafter *The Principles*). The publication history of *The Principles* is troubled: it appeared posthumously, in translation, with editors noting that some parts of the original text (a notebook of Conway's) were illegible (Hutton 2004). The original notebook was also lost, meaning no cross-checking was possible, and so the Latin translation from 1690 is the *de facto* authoritative version of the work. To add to these interpretative difficulties, Anne Conway lived a somewhat private life. She was not a public figure, largely due to her severe illness, which debilitated her for most of her adult life. All of these factors (a small, troubled corpus, a lack of public avowals of support, being relatively restricted in seeking out other thinkers due to being bedridden) have made interpreting her philosophical allegiances and her sources of influence particularly difficult.

A large body of literature investigates these questions, both historically and systematically. This scholarship provides a list of 'usual suspects' when it comes to identifying authors who might have influenced Conway. Often, claims about influence and similarity are also part of placing Conway in one or another tradition in intellectual history. A few examples from the literature are provided below:

> "[…] we could potentially regard her as an early Quaker theologian […]". (Head 2020, p.113)
> "[…] *The Principles*, which incorporated both Quaker sensibilities and Kabbalah doctrines […]". (White 2008, p.38)
> "[…] *The Principles* […] is a fascinating and radical philosophical treatise that sets forth a vitalistic philosophy derived largely from the Lurianic Kabbalah." (Coudert and Corse 1996, p.xxix)
> "Her book is carefully argued, scholastic in its mode of presentation, and shows the imprint of van Helmont's thought at every turn" (Coude*rt 1975,* p.643)

However, some scholars also explicitly object to some of the authors proposed as sources of influence for Conway. Peter Lopston interprets Conway as a rationalist metaphysician and more as a frontrunner of Leibniz than as being influenced by More or van Helmont: "The Principles sets out a metaphysical system of proto-Leibnizian stamp, articulated *with a clarity of thought difficult to discern in either van Helmont or More"*. (Lopston 1995, 144, emphasis mine)

[29] To be found in *The Conway Letters* (1992), edited by Marjorie Nicolson.

In her biography of Conway, Sarah Hutton insists on the Platonic roots of Conway and suggests that there is an undeniable proximity to Henry More (1614-1687) and to Cambridge Platonism more generally (Hutton 2004, p.6-8). Emily Thomas suggests a proximity between More and Conway as well, via an investigation of Conway's views on space and time (Thomas 2017, p.1007-1008). Not all of these claims are mutually exclusive and it is well understood that a large number of the authors identified in the literature must have had some influence on and points of similarity with Conway's *Principles*. Still, I take it from the above claims that Conway's influences and historical placement are contested.

In this chapter, I aim to contribute to this debate by using some of the methods introduced in Chapter 1, namely I will generate high-dimensional semantic models of the usage of specific words. Then I extract the similarities between Conway's *Principles* and other works. Higher similarity, I will argue, is an indicator of some substantial relation of influence existing between two works, whereas very low scores suggest that there is no such relation of influence between the works. Such scores will be generated between *The Principles* and each of the works the literature advances of being sources for Conway. The investigation of these scores will suggest that some of the figures and traditions indicated in the existing literature could be re-considered in their actual proximity to Conway's thoughts (Cambridge Platonism, Quakerism, Kabbalism), whereas some are confirmed in their current status (Francis van Helmont) and others are closer than expected (namely, the mechanistic rationalism of Hobbes and Descartes).

Conway will turn out to be close to the way of speaking of the Cartesians, and shows how not only a way of speaking can "be in the air" but can run from one thinker to the other. Yet, it also shows the strength of these schools' semantic impact, despite their coming to wildly differing conclusions; Conway, writing in relative seclusion, remains in the Cartesian semantic sphere of influence. To escape a sphere of influence it is not enough to decide to want to see the world anew; you need a broader group with whom to develop a new way of speaking about the world that will allow a conceptual distance to be developed and sustained over time. Instead, Conway shows us an example of a thinker who works with extreme doctrinal creativity to further develop the conceptual apparatus of Cartesian mechanicism. She disagrees with Descartes and, yet, tries to answer Cartesian questions with Cartesian terminology (Hutton 2004, p.52). A person that does not require a broader context for moving away from a decided way of speaking, suggests being an exceptional semantic trailblazer–a category of works which I will examine next chapter.

Section 4.2 gives a brief overview of the figures and texts that the literature suggests to be close to Conway's thoughts. This includes a defence of the choice of texts to be investigated in the experiment. Section 4.3 provides an overview of the method

and its rationale. To give further substance to the meaning of the semantic methods, they are contrasted with stylometric and term frequency-inverse document frequency (tf-idf) analyses (Holmes 1998). By preferring the semantic modelling of the texts' profile that has been introduced in Chapter 1, I provide the interpretation that the similarity scores obtained are indicators of relations of (semantic) influence. In section 4.4, I introduce the experiment and provide the results and, in 4.5, I analyse the results in comparison to the claims found in the existing literature. Finally, in section 4.6, I conclude with some considerations about the strength of these results and how they could best be interpreted.

4.2: Conway's Sources

In this section, I describe the choice of the works that I will analyse from the point of view of their semantic similarity to Conway's *Principles*. The choice of these works and authors is based on a combination of practical considerations, publication language, and their position in the secondary literature.[30]

I preferred the Latin versions of the works, which I then compared to the 'original' Latin edition of *The Principles* published in 1690. Conway could read Latin, although she did not write originally in Latin (Hutton 2004, p.36). However, some of the authors identified in the literature did not publish in Latin, but in English. For these authors, I will make a semantic comparison with the translation of *The Principles* that was prepared in 1692 by an anonymous J.C.

The similarities derived between the 1692 translation and the original English works by Keith and Cavendish, however, need to be assessed carefully in how they relate to the similarities derived based on the Latin 'original'. There might be semantic similarities that derive from the translators' activity, in addition to the fact that certain words in one particular language turn out to be generally more similar across texts than in another language. I conduct a small experiment to alleviate some of these worries by comparing the (original) English language version of van Helmont's *Two Hundred Queries* (1684) as well as its Latin translation *Problemata*, published in the same collection of works as Conway's Latin text in 1690. The discrepancy between these scores will provide some indication on how to interpret the relative similarity of the English and Latin texts.

[30] A recent new addition to the list of potential routes of influence is provided by Doina Rusu (2021), who argues that Conway's concept of spirit is derived from the tradition of renaissance vitalism. Figures like Tomasso Campanella (1568–1639) and Francis Bacon (1561–1626) might be considered as good candidates for analysis in the way executed below. However, various time restrictions have prevented me from including these actors in the experiment.

Finally, when an author is identified in the literature as a potential influence on Conway's work, preference will be given not only to texts that are available, but also to texts that are on similar topics as Conway's *Principles*.

4.2.1: The Usual Suspects. Mentor: Henry More and Cambridge Platonism

Henry More, one of the leading figures of 'Cambridge Platonism', was first Conway's mentor and later a long-time friend of her. He introduced Conway to mechanical philosophy through translations of Descartes and through his own writings. Furthermore, he was an intensive collaborator of Conway on theological and religious topics, including reading the Jewish Kabbala and interpreting those doctrines in line with Christian ones. Although these topics would eventually lead to disagreement among the two (Conway being more willing to follow along Kabbalistic lines which possibly connected to her eventual Quaker conversion), More remained an important source of philosophical input for Conway.

In regards to his influence on Conway's thoughts throughout her life, there can be no doubt that More was of importance to Conway's thought, given his early overt intellectual activity directed at her. However, their disagreements towards the end of their life also indicate that Conway's thoughts had developed in a different direction: that of van Helmont and the Kabbala, or else, in the direction of the Quaker religious doctrines, depending on interpretations.

Conway's agreements and disagreements with More are of particular interest to modern interpreters. Hutton has argued that Conway should be placed squarely in the Platonic tradition, more specifically in the Cambridge Platonist one. Yet, some specialized literature has pointed out their philosophical divergencies, like Jonathan Head in *Anne Conway and Henry More on Freedom* (Head 2020). Given the claim by Head that More's outlook on freedom in the *Enchiridion Ethicum* diverges from Conway's views, whereas Emily Thomas has noted (Thomas 2017) agreements about space and place between Conway and More's *Enchiridium Metaphysicum,* these two works of More will both be used for comparison with Conway's *Principles*. Both works are retrieved from a scan of the of More's *Opera Omnia* (1679).

4.2.2: Friends: Van Helmont and the Kabbala

Francis van Helmont was a medical practitioner and enthusiastic philosopher. After joining Ragley Hall, where Conway lived, as her doctor, and failing to cure Conway from her debilitating headaches, he stayed there as a personal friend of Conway for nine years.

Van Helmont was a thinker who was influenced by a multitude of traditions. Alchemical traditions, which he seems to have taken from his father, Jan van Helmont, were central to his thought, just as Jewish (Lurianic) Kabbalism was. Van Helmont introduced Conway to Christian Knorr von Rosenroth, who has been pivotal in the introduction of kabbalistic thought in Europe through his translation of Kabbalistic texts into Latin with his *Kabbala Denudata* from 1677 onwards. A nine-year long intellectual friendship is, of course, a very fertile ground for the cross-influencing of thoughts. Moreover, the Kabbala explicitly figures in Conway's *Principles*, most visibly in the annotations in Chapter 1. However, these annotations have been brought under scrutiny (Reid 2020), as they might have been an addendum by the editor (Franciscus van Helmont), especially since the parts of the work from which many were quoted (Rosenroth's later volumes of the *Kabbala Denudata*) were not yet published when Conway died. Although she may have been well acquainted with the text through discussions, citation might have still been impossible for her.

There have been less fine-grained analyses of Conway's (dis)agreements with van Helmont and the Kabbala. Yet, doctrinal agreements are noted throughout the literature (Coudert 1975). In addition, there is no biographical reason to assume that van Helmont was not of influence. There are no explicit disagreements between van Helmont and Conway that we find in the remaining letters, and van Helmont was himself quite happy to see continuities with his own thought and Quakerism, to which he also converted. Whereas Conway's religious conversion in the last years of her life led her away from More, no such thing happened in van Helmont's case.

For van Helmont, I will use his *Two Hundred Queries Moderately Propounded Concerning the Doctrine of the Revolution of the Humane Souls and its Conformity to the Truths of Christianity*, with which Conway was familiar. This text has both an English original (1684)[31] and a Latin translation (*C.C. Problemata de revolution Animarum Humanarum* 1690). The Latin translation occurs in the same publication (*Opuscula Philosophica*) as Conway's Latin *Principles*. For reasons discussed above, I will compare the English and the Latin translations with each other. This availability is one of the main motivators to pick this text by van Helmont, as, in general, the dating of his works is not trivial. Secondly, as representative of 'Kabbalism', I will use the one volume of Rosenroth's *Kabbala Denudata* that I could find (Part 2, Vol. 2, 1684). This text may not have been published during Conway's life, but she was part of its publication process and discussed the Kabballah mostly in this context with van Helmont and others.

[31] The text, however, was written earlier, therefore its publication date is no indication of the fact that Conway couldn't have had knowledge of it (Hutton 2004, p.149-150).

4.2.3: Faith: The Quakers and George Keith

The final years of Conway's life were marked by both the writing of her treatise and her conversion to Quakerism. This conversion led to much unease in her social circles, in particular with More. George Keith was the Quaker thinker that was most prominent at Ragley Hall and with whom Conway, but also More, Rosenroth and van Helmont, had extensive interactions and discussions. Hutton summarizes: "Of all the Quaker leaders, George Keith played a pivotal role in Conway's decision to convert. […] Keith's writings, therefore, give us a valuable reference point for the development of her mature thought" (Hutton 2004, p.188)

It is Keith's *Way Cast Up* (1677) and *The Way to the City of God* (1678) that seem to have been taken up by Conway. In this latter work, for example, Keith proposes a view of Christ as 'mediator', which has strong resemblances to Conway's concept of Christ. This manuscript was already available in OCRed format, which motivated my choice. Keith has only published works in English, so his "*The Way to the City of God*" will be compared with the 1692 English translation of *The Principles*.

4.2.4: The Less Usual Suspects

Besides these above mentioned six works by various authors and two works by Conway (the original Latin publication in 1690 and its subsequent 1692 English translation), I will look at another five which have been indicated as possible sources of influence.

Given Conway's general description as an early modern rationalist and her explicit mentioning of Spinoza, Descartes and Hobbes, it is worthwhile to compare her work to texts by these authors. I extracted three Latin texts on philosophy by them: for Spinoza, his *Opera posthuma* (1677) in its entirety; for Descartes, his *Principia (1644)*; and for Hobbes, *De corpore* (1655). Not all of Hobbes' work was originally in Latin, nor was it all on natural philosophy and metaphysics, which drove me to choose *De Corpore*. For Descartes and Spinoza, the above-mentioned are (or include) canonical texts. There is uncertainty in the literature whether Conway had access to the manuscript of the *Ethics* during the period in which she is generally placed to have written (up to 1675) (Coudert 1996, p.xxxviii). It is argued by Pugliese (2019) that Conway had no access to the entirety of the *Opera posthuma* during the writing of her own treatise, however, that she had access to the *Tractatus theologico-politicus*, and parts and summaries of earlier versions of the *Ethics*. If she had no access to Spinoza's work, the explicit mention of Spinoza in the preface and the final chapter are other signs of belated editorial activity, or would be only statements against Spinozism 'as atheism'.

Another author named in the literature is Margaret Cavendish (Hutton 2004; Detlefsen 2018). There is no evidence of interaction between the two thinkers; however,

Cavendish was most likely known by Conway and Conway possibly read her. Parallels between the authors' thoughts and social circumstances have been noted (Detlefsen 2018). As such, I chose to include her via her work *Grounds of Natural Philosophy* (1668), as no Latin original text was ever written by Cavendish.

Franciscus van Helmont's father has been mentioned earlier. His thought and that of his son are claimed to intersect (Hutton 2004, p.140-155). Therefore, J.B. van Helmont might prove to be to be a direct or an indirect influence via his son, on Conway. Practicalities related to finding scanned manuscripts have made the choice fall on his *Ortus medicinea* (1655).

Finally, I will examine one additional work, the *Philosophia vulgaris refutata*, written by an anonymous J.G. (not to be confused with the anonymous translator of Conway's *Principles*, J.C.), which was published in *Opuscula philosophica* (1690), together with van Helmont's *Problemata* and Conway's *Principia.* I include this in order to investigate how extensive the influence of sharing a printer might have been, even if this work is never studied in the literature as an important source for Conway's thought. These considerations give a total corpus of twelve works which will be analysed in their semantic similarity to either the English or Latin version of Conway's *Principles*.

4.3: Similarity of Texts: Semantic and Otherwise

To computationally investigate relations of influence between Conway and the previously mentioned works, I will use the measures of semantic similarity that have been introduced in Chapter 1. I will argue that we can take this to be indicative of the occurrence of a relation of influence. To reiterate, this method models the *semantic fingerprint* of a particular word in a text with the intention to model the *meaning* of particular words in particular texts. Two texts can be analysed from the point of view of their respective usage of a particular word of interest. As a way of introducing my reasons for taking vector semantics as indicative of (particular types of) relations of influence, let me shortly look at two related methods traditionally used for deriving similarities between texts.

The *Re-Counting Plato* project attempted, through an analysis of a number of stylometric features and the similarities with regards to these features of different bits of text, to identify whether certain works should be attributed to Plato or not and to suggest a clustering of works into groups of high shared similarity, which could then be used to suggest a chronology of Plato's works (Ledger 1989). The variables, or features, may appear as odd. For *Re-Counting Plato*, they include properties like: 'how often does a certain letter occur as the penultimate letter in a word' and 'how often does a certain letter occur in words' (Ledger 1989). This approach, however, is wholly in accordance with the rationale that underlies the field of stylometry. Stylometry operates on the

assumption that every author will have an authorial fingerprint in their texts. This fingerprint is one that can be found in the style (form) of the text, irrespective of its contents (Boyd and Pennebaker 2015, p.570-571). What features are indicative of a specific author can vary and does not depend on any conscious action by the author. The author's style shows itself even when attempting to impersonate another person or to remain anonymous, as, in fact, stylometry is applied for exactly such cases (Afroz *et al.* 2014). Lacking conscious intervention in this 'personal style', there is no reason to assume that the features by which we find authorial style need to 'make immediate sense'. So, preferring certain letters in certain locations of the words might not be the sort of thing we consciously consider when we write; yet, they might turn out to be part of our own personal style.

Another method often used is 'text frequency – inverse document frequency' (tf-idf). For information retrieval and text mining, tf-idf is used to derive yet another type of similarity scores between texts (Ramos 2003). Tf-idf scores the similarity between texts highly when the same words occur often in both texts. Tf-idf does not provide a model of the meaning of the words used, but tries to see whether two texts are discussing the same sort of issues and attach similar importance to similar words. It is for example used by library search engines to find texts for which certain search queries: 'bodies in motion' will return texts in which 1) those words occur very often and 2) will weigh the generally less frequent words ('bodies', 'motion') more highly than the generally frequent word ('in'). Texts which score highly among each other on tf-idf, are texts which will have relatively many *specific* words in common (i.e., they share words that are relatively less frequent in the whole corpus, but more salient for specific discussions). Tf-idf thus ideally pick out pairs of texts that are on the same issues or that share a certain way of using the language.

My proposed method, which traces semantic similarity of words across texts, differs from both of the above methods. Although there will be no way to claim that the method proposed to uncover semantic similarity will not pick up on stylistic similarities, it is ideally constructed so as to disregard personal style (meaning it *ought* to be worse at author identification tasks). Similarly, semantic similarities cannot be reduced to a question of what the text is about. Texts can be on the same topic (both discussing nature) while using the term 'nature' very differently from each other. I aim for semantic similarity because stylometry and tf-idf don't tell us about relations of influence. The goal here is not to argue that some texts are actually written by the same author, nor that they are on a similar topic or use similar words, but that it is likely that there is a relation of *semantic influence* between two texts, which is more apt to trace semantic influence between texts than stylometry and tf-idf. We should not expect semantic influence to impact the authorial fingerprint (again, the rationale of stylometry is to be able to, for example, differentiate between a translator and original author, which ought

to be semantically quite proximate, but different in style).[32] Text-to-text influence might impact topic selection of texts, or giving weight to specific terms. This weaker sense of influence would then tell us that the one text might have influenced another to also consider the same broad topic and use the same terms. This can happen without any extensive consideration of the influencing work itself. A comparison between Conway's tf-idf similarity and semantic similarity to the other works will be added in section 4.4 to bring out these algorithmic differences and clarify the interpretation of the semantic similarities as influence.

Nevertheless, this leads us to look at the idea of texts influencing texts. I propose that there are three important things to look for when investigating influence. Firstly, for influence to occur between texts, there needs to be some possible contact between the influencing text and the influenced author. To claim that Descartes' *Principles* influenced Leibniz' *Monadology* (1714), there should also be some (possible) line, starting with *The Principles* which would have allowed Leibniz to have gotten into contact with the ideas contained in there (most easily, by reading *The Principles*, but also by hearing from another about the work or reading another work influenced by that book).

Secondly, the influences we are interested in are partly consciously and partly unconsciously implemented. The former situations are cases like explicit reference, crypto-citations, the implementation of a definition or the implementation of a turn of phrase. However, we also allow for influence relations to run between authors where the one influenced is unaware of this occurring. Ideas, meanings, metaphors and arguments can also work their way into a thinker's thought without the thinker being wholly aware of this happening. In other words, one can influence someone else through salient or non-salient aspects of one's writing.

Thirdly, influence is usually the result of properties of a text that are meaningful to a reader of that text, although sometimes not. Usually, what the influence consists of (meaning shifts, acceptance of conclusions, incorporation of substantial metaphors) is the effect of those features of the text that the reader picks up on and considers meaningful communications from the text. If not immediately, upon being presented with these features, the reader would still be inclined to say it is a substantial part of the text's contents. Most forms of semantic influence via text occur through meaningful and systematic properties of that text and not via non-meaningful (yet also systematic) features of a text. That is to say, a philosopher's ratio of using the letter 'e' as penultimate letter in words (as investigated in stylometry) will most likely not be a motor of influence on the reader's own writings due to its hidden nature, but for example, a

[32] See Jan Rybicki's *The Great Mystery of the (Almost) Invisible Translator* (2012) and his and Heydel's *The Stylistics and Stylometry of Collaborative Translation: Woolf's Night and Day in Polish* (2018) for a discussion of how translator style is still an ongoing problem in stylometry.

feature like ‘matter’ and ‘motion’ occurs in close proximity to each other very often in mechanist texts’ is potentially likely to influence a reader. This also means that in many cases a later reader or scholar can interpret and analyse these routes of influence, which would be harder for the stylometric analyses.

Semantic similarities mesh nicely with property 2. Semantic contexts of words are sometimes consciously adopted (as the ‘matter’ and ‘motion’ case shows) and sometimes simply find their way into a work implicitly. The most common examples of bodies are not explicitly part of the definition of ‘body’ yet are consistently transmitted throughout the period. Property 3 is also accounted for: word contexts are most often well understandable categories with sensible interpretations available for a reader of the text. Two works being particularly similar in their use of ‘body’, because all of the situations where body occurs are similar across the two works, is an interpretable feature of the text. It is a semantically-laden feature of the text, one that signals a particular usage (and meaning) of key terms.

However, the similarity relation does not tell us anything about property 1. It is this which makes the relation little more than an indicator: there can be cases of high similarity, but a lack of causal linkage between the text and the author that writes the text that is to be influenced. This is an additional reason to start our investigation with the writers who were proposed as sources of influence on Conway’s work by the literature. In these cases, requirement 1 is accounted for. When this is not accounted for, it is safer to use semantic similarity as an indicator of influence only in aggregated contexts (as I will do in the next chapter).

Given that property 1 has been met, I then take semantic similarity to be a strong indicator for an intellectual/semantic influence relation to exist between two texts that score as highly semantically similar and a strong indicator for a lack of influence if they score particularly low. If a text has been influenced by another text which was known to the former text’s author, one would expect some semantic overlap to occur between the two texts. In lieu of any such semantic overlap, it is most likely that the author did not adopt much from the text read.

A high score, however, does not necessarily indicate a unidirectional relation of influence. Influence can be a two-way relation as long as both authors would have had access to each other’s thoughts. In addition, if we find a triad of high similarity scores where one of the works is significantly earlier than the other two, this might be indicative that the other works share an influence (and have not necessarily influenced each other). Another way of putting this is that I only consider cases of direct influence

here and other cases (indirect influence, shared influence, bi-directional influence) are here not considered, except insofar as they speak from the results themselves.[33]

4.4: Experiment Details and Results

The experiment is set up to check the similarity score between the Latin *Principles* and the other 10 works. In addition, the English *Principles* will be scored against the *Two Hundred Queries*, *Ground of Natural Philosophy* and *The Way to the City of God*.

In order to create a meaningful frame of reference for assessing these results, I introduce a parallel benchmark corpus, derived from the broader corpus of natural philosophical works used in the ERC project. This benchmark I derive from the Latin primary corpus, and consists of a random sample of 50 works between 1623 and 1727 (dates starting slightly before and somewhat after Conway's birth and death). The purpose of scoring these works is to generate a baseline score against which the works relevant for assessing influences on Conway can be compared. By revealing an average score, I can more easily set a threshold for similarity values, below which I assume that no specific influence is at play, but simply a more general and broader sharing of style and semantics proper to the period. However, all similarity scores above this threshold might in fact indicate that more than this general sharing is at stake, and this is where I shall direct my attention. A base-line will be produced by checking the Latin *Principles* against the benchmark corpus. These similarity scores will be averaged and the individual results will not be discussed.

All of the scores will be derived for a number of keywords that are central to Conway's *Principles* and that are also generally ubiquitous in early modern philosophy. These terms are 'anima', 'causa', 'corpus', 'deus', 'locus', 'natura', 'ratio', 'species', 'tempus', and 'pars' in Latin.[34] For the English, I use their translations.

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[33] That is not to say there might not be ways of differentiating between these different cases computationally. In particular, it could be fruitful to think of cases of indirect and shared influence as a question about triads of works (A, B, C) that all exhibit high similarity amongst each other. Assuming A to be prior to B and B prior to C, the question becomes whether C is similar to A due to the influence of A itself or the mediating influence of B. Similarly, the question arises whether C is similar to B because of B's influence on C, or due to C sharing A as a source with B. Three cases emerge if we could give a satisfactory answer to these two questions based on relative similarities between A, B and C: i) A influenced C and B influenced C (C is similar to A and B due to direct influences); ii) A influenced C but B did not influence C (B and C are similar due to shared influence); and iii) A did not influence C but B did influences C (there is an indirect influence via B from A to C that explains their similarity).

[34] In contrast with other selections, these terms have been extracted based on domain knowledge about Conway's philosophy, and not via topic modelling. This means we should take some care in comparing these scores to the stability scores extracted in previous chapters as these consider (somewhat) different words. This is only an issue for the absolute comparison of these values,

The results are presented in Tables 4.1 and 4.2:

Latin Works	**Conway 1690**
J.B. Helmont, *Ortus medicinea* (1655)	171.8
Hobbes, *De corpore* (1656)	365.5
Descartes, *Principiae* (1664)	334.6
Spinoza, *Opera* (1677)	273.2
More, *Ethicum* (1679)	273.5
More, *Metaphysicum* (1679)	297.6
Rosenroth, *Kabbala* (1684)	242.9
F. van Helmont, *Problemata* (1690)	353.7
J.G., *Vulgaris* (1690)	311.6

Table 4.1: Similarity results with Conway's Latin 1690 version

English Works	**Conway 1692**
Cavendish, *Grounds* (1668)	325.6
Keith, The *Way* (1678)	269.8
F. van Helmont, *200 Queries* (1684)	361.4

Table 4.2: Similarity results with Conway's English 1692 version

In addition, I found that (1) the average similarity obtained between Conway and the 50 works in the benchmark corpus is 301. This score will signify the "average" similarity to Conway that could be expected merely from being in a corpus of natural philosophy. Additionally, (2) the total average similarity among all 50 of these works themselves is 292 (which is higher than the total Latin corpus average found in Chapter 2, most likely due to the smaller period considered and selecting only from the primary corpus). This score signifies the average similarity works within a corpus of natural philosophy have to each other. Before turning to the interpretation of these results, two more formal properties of the results can be reviewed.

Firstly, the two scores for van Helmont's works (English and Latin) are very close to each other. This tentatively suggests that the English and Latin absolute scores can be somewhat safely compared across the language barrier. This will allow me to take the English results along in the total ranking of works with Conway's *Principles*. However, in

which is not necessary for the investigation of Conway or the comparison of particular influences. By choosing terms vetted in relation to Conway, the similarity scores can be expected to better reflect the link to Conway specifically.

lieu of more robust experiments, care should be taken when interpreting these specific results.

Secondly, there is no very large difference between Conway's average connection strength across a random sample of 50 works in the benchmark corpus. This suggests that this score – approximately 295 – is the score we can take to be the average. This also provides us with a baseline against which we can interpret the results for the specific authors of interest.

A ranking of all the results is provided in Table 4.3:

1.	Hobbes, *De corpore* (1656)	365
2.	F. van Helmont, *200 Queries* (1684)	361
3.	F. van Helmont, Problemata (1690)	354
4.	Descartes, *Principiae* (1664)	335
5.	Cavendish, *Grounds* (1668)	326
6.	J.G., *Vulgaris* (1690)	312
7.	Conway average	301
8.	More, *Metaphysicum* (1679)	298
9.	Sample corpus total average	292
10.	More, Ethicum (1679)	274
11.	Spinoza, Opera (1677)	273
12.	Keith, The Way (1678)	270
13.	Rosenroth, Kabbala (1684)	243
14.	J.B. Helmont, Ortus medicinea (1655)	172

Table 4.3: Ranked similarities with Conway

This ranking suggests two groups of works: those that score lower and those that score higher than the Conway average. However, to provide substance to this intuition, a statistical test needs to be run between the two samples: the scores from which the Conway average is derived and all the other sets of scores from which the other averages are derived. For Hobbes-Conway we have, for example, 10 datapoints, 1 for each keyword,[35] which are averaged to derive this score. The Conway average score was derived against 50 works, so we get 50 works * 10 keywords = 500 datapoints. Using a two-sample z-test (a standard statistical test for comparing the means of two populations) I check each pair of scores. To see whether the averages are indeed

[35] The similarity derived for one keyword will depend also on the similarity found along the other checked keyword's dimensions. However, given that there are tens of thousands of these dimensions, I opted to disregard this dependence and assumed independence for the statistical test.

statistically significantly higher or lower I use a significance level (α) of 0.05. From this we reject the null-hypotheses for Hobbes, F.v. Helmont in Latin and English, Descartes, More's Ethics, Spinoza, Keith, Rosenroth, and J.B. van Helmont. By contrast, the null-hypothesis (that the two averages are the same) is accepted for 3 works: Cavendish, J.G., and More's Metaphysics. This splits up the ranking in three parts, as we can see in Table 4.4:

1.	Hobbes, *De corpore* (1656)	365
2.	F. van Helmont, *200 Queries* (1684)	361
3.	F. van Helmont, *Problemata* (1690)	354
4.	Descartes, *Principiae* (1664)	335
5.	Cavendish, *Grounds* (1668)	326
6.	J.G., *Vulgaris* (1690)	312
7.	Conway average	**301**
8.	More, *Metaphysicum* (1679)	298
9.	Sample corpus total average	292
10.	More, *Ethicum* (1679)	274
11.	Spinoza, *Opera* (1677)	273
12.	Keith, *The Way* (1678)	270
13.	Rosenroth, *Kabbala* (1684)	243
14.	J.B. Helmont, *Ortus medicinea* (1655)	172

Table 4.4: Ranked results, colored when significantly divergent from the Conway average

To comparatively bring out the particularity of the semantic outcomes, a similar table was extracted using the tf-idf method discussed in section 2. These scores are normalized between 0 and 1, and a 1-sample Z-test is used for checking whether the difference with the average is statistically significant:

1.	More, *Metaphysicum* (1679)	0.592
2.	Hobbes, *De corpore* (1656)	0.588
3.	J.G., *Vulgaris* (1690)	0.576
4.	More, *Ethicum* (1679)	0.571
5.	Spinoza, *Opera* (1677)	0.569
6.	Descartes, *Principiae* (1664)	0.531
7.	J.B. Helmont, *Ortus medicinea* (1655)	0.493
8.	**Conway average**	**0.473**
9.	F. van Helmont, *Problemata* (1690)	0.473
10.	F. van Helmont, *200 Queries* (1684)	0.449
11.	Keith, *The Way* (1678)	0.439
12.	Cavendish, *Grounds* (1668)	0.420
13.	Rosenroth, *Kabbala* (1684)	0.354

Table 4.5: Ranked, Z-tested tf-idf similarity scores

Firstly, note that the tf-idf and semantic similarity results provide a significantly different picture. Given that tf-idf tells us something about the overlap in types of words used in two texts (without considering the meaning of those words or the shifts that these might undergo from author to author), the tf-idf results in Table 4.5 need to be interpreted differently from the results of Table 4.4. A low similarity with Keith in Table 4.5 ideally suggests that Conway and Keith wrote about different topics and less ideally that Keith and Conway didn't use similar (infrequent) words in their writings. The low semantic similarity score between Keith and Conway, however, ideally tells us that Keith used the same (key)words in significantly different ways. This suggests that Keith and Conway employed their language from within a different framework and they mean and associate different things with the same terms. This, I argue, entails that it is unlikely that Keith is a source of Conway's thought: Keith's work has not found its way into the conceptual apparatus of *The Principles*. Tf-idf and semantic similarity thus indicate two different (interesting) properties of pairs of texts. In addition, the fact that they differ significantly shows the value of not using these interchangeably. Instead of that one should provide ways of interpreting both types of results. As argued, I take the results of Table 4.5 not to relate to my original question. It is the results in Table 4.4 that will be interpreted in the coming section.

4.5: Interpretation

The results show a number of interesting things. First, we might have expected that works identified in the literature as potential influences on Conway's thought would all score higher than average. However, the results do not show this. A number of the

identified works scores lower than Conway's average similarity. And this is not merely an artifact of that Conway is so similar to the corpus – the sample corpus total average semantic similarity score is higher still than many of the identified writings. More's *Enchiridion ethicum*, Spinoza's *Opera posthuma*, Keith's *The Way*, Rosenroth's *Kabbala denudata* and, finally, J.B. van Helmont's *Ortus medicanea* all score lower than Conway and the sample corpus do, on average. The suggestion that follows from this is that these works have not significantly influenced Conway's *Principles*, despite the biographical evidence to the contrary that exists especially for Keith, Rosenroth and More. All of these authors have had extensive discussions with Conway throughout her life and, as such, one might have expected that the works of these authors might be semantically similar to *The Principles* on the assumption that the authors had (been) influenced (by) Conway.

Second, among the above-average scores we find works by authors for whom such intimate contact was not the case. Conway had no extensive personal contact with Hobbes or Descartes. The only author here who has had extensive contact was Francis van Helmont, her good friend, intellectual collaborator, and eventual posthumous editor. That Hobbes and Descartes were not personal acquaintances of Conway does not imply that Conway was not aware of them or their works. *The Principles* itself names these authors and their works as principal opponents. In addition, there are letters which indicate that her mentor More had introduced her to mechanical philosophy at a young age.

Third, we find that Cavendish and J.G.'s works are picked out by the Z-tests as not significantly deviating from the average similarity Conway scores throughout the sample corpus. In the case of J.G. this is excellent news: it suggests that there is no real connection between the two works, meaning that their shared printer and publisher was likely uninfluential in regards to the content of Conway's work. A strong connection would have indicated the contrary casting doubt on how representative Conway's published work is for her thought. Similarly, Canvendish's score falls along the same lines: her relation to Conway was tenuous and not much insisted upon in the literature. As such, finding her as not more or less connected than any other member of the corpus agrees with the expectation that a random author from the corpus would fall somewhere around Conway's average connective strength.

I suggest the following interpretations. Many of the authors that have been identified based on biographical information as relevant to Conway's thoughts have scored quite low. By contrast, a number of mechanist metaphycisists have scored particularly high, despite Conway having no strong personal relations with these authors. This agrees with one of the suggestions I presented in the introduction: Lopston would prefer to differentiate Conway strongly from the likes of van Helmont and More and posit her as best characterized as a rationalist/mechanicist metaphycisist of the

seventeenth century, without any further need to place her more firmly in other traditions (Lopston 1982, 144). This reconstruction meshes quite well with the results: More, Rosenroth, Helmont Sr., and Keith all score poorly. However, two of the datapoints do not appear to confirm this suggestion: van Helmont does come out as high scoring, while Spinoza (also one of the rationalist Descartes inspired and mechanism interested metaphycisists) does not. For Spinoza, a chronological explanation can be offered: given that Conway might not have come across his texts extensively (Coudert 1996), lower similarity can be expected. Another reason might derive from the more multifaceted nature of the *Opera posthuma*, consisting not only of works in natural philosophy, but also a work of political philosophy (*Tractatus politicus*), and a compendium of Hebrew grammar, unlike many of the other works being scored. A further investigation of the similarity of Conway's work with different works of Spinoza (instead of their aggregation in the *Opera posthuma)* could be executed to ascertain this.

However, the similarity with van Helmont cannot be as easily dismissed. Three options for interpretation present themselves. First, van Helmont and Conway were intellectual collaborators for many years and it is to be expected that their vocabularies get attuned to one another. Importantly, in contrast with More, for example, this collaboration remained sustained up to the end of Conway's life (the period in which she wrote her treatise), unlike her collaboration with Keith, for instance. This means that Coudert's suggestion according to which "[h]er book is carefully argued, scholastic in its mode of presentation, and shows the imprint of Helmont's thought at every turn" (Coudert 1975, p.643) can be partly validated by these results. Van Helmont and Conway share a large part of their conceptual vocabulary in their published works. However, a second, alternative option is also available given van Helmont's function as editor and translator of Conway's *Principles*. Since the original is lost, there is no way to check the influence that has been exerted by him at this point.[36] Even so, (part of) the similarity could be explained via reference to van Helmont's editorial function. Read in a loose way, Coudert's suggestion is borne out: however it occurred (through conversation or editing), Conway's work bears van Helmont's mark and, given their synchronous writing, van Helmont's work also bears Conway's.

Nevertheless, yet another, third, scenario comes up if we look at the scores van Helmont has with the other works investigated, presented in Table 4.6:

[36] See Reid's *Anne Conway and Her Circle on Monads* (2020) for a more fine-grained discussion of editorial influence in *The Principles.*

1.	Conway, *Principles* (1692)	354
2.	Conway, *Principia* (1690)	354
3.	Cavendish, *Grounds* (1668)	349
4.	Keith, *The Way* (1678)	306
5.	Hobbes, *De corpore* (1656)	285
6.	Descartes, *Principiae* (1664)	276
7.	More, *Ethicum* (1679)	267
8.	Rosenroth, *Kabbala* (1684)	262
9.	J.G., *Vulgaris* (1690)	257
10.	Spinoza, *Opera* (1677)	228
11.	More, *Metaphysicum* (1679)	206
12.	J.B. Helmont, *Ortus medicinea* (1655)	150

Table 4.6: Van Helmont results, ranked low to high

What we find is that van Helmont actually connects most strongly with Conway, followed by Cavendish, Keith, Hobbes and Descartes. This suggests yet another possibility: that van Helmont is more closely related in his thought with the new mechanical philosophy than his cited interests in Kabbalism and the Loch Ness monster (Lopston 1982, p.144) might suggest. Indeed, out of the eleven Latin works, Hobbes, Conway, and van Helmont seem to form something of a coherent unit with relatively high scores amongst each other, to which we could add Descartes, except for his relation with van Helmont. If that is the case, then Lopston might be wrong, but in a different way: not because Conway lacks affinities with van Helmont, but because van Helmont is not exactly the sort of philosopher Lopston takes him to be.

Three conclusions have been presented up to this point. First, Lopston's suggestion to read Conway as a rationalist metaphysicist 'in spite of' her personal relations seems partly vindicated by the unexpected proximity of Conway to Hobbes and Descartes. It appears that mechanicism, despite her insistence on matter being alive, remains a philosophical school from which she borrows much terminology. Second, the suggestion that Conway's response to Spinoza might have been a late addition and that she was not deeply acquainted with his philosophy is supported. Although this would require further investigation by the comparison not only of the entire *Opera posthuma*, but parts of it, to ensure that the dissimilarity doesn't derive from the *Opera posthuma's* different sorts of philosophical content. Third, I've suggested three different roads of understanding Conway's proximity to van Helmont. One is based on mutual influence, one on editorial influence, and one on a shared influence from Descartes and Hobbes. The second would fit well with Lopston's general characterization, the first with Coudert's characterization. I do not take the results to favour either of these three options.

Finally, a note on the low scoring work is in order. Given that Conway is discovered often via her acquaintance with More and her extensive personal history with More, as has been brought out in the Conway Letters, it is natural to seek to understand Conway from the perspective of the better-known More. Similarly, the radicality of her eventual conversion to Quakerism and her extensive and prolonged interest in the Kabbalah suggest to understand her from the viewpoint of these traditions. I take the above results as a warning against taking *too seriously* the biography of philosophers for the tracing of sources. Of course, (mediated) acquaintance is a necessary condition for influence to occur. But it is not clear whether this also increases the chance that more extensive (semantic) influence will occur when the acquaintance grows more extensive. Conway's thoughts have developed in a different direction than one would have expected given More as her mentor. A pervasive interest in the Kabbalah does not imply that Conway's conceptual apparatus has turned Kabbalistic and an eventual conversion to Quakerism similarly does not sediment itself into her conceptual vocabulary.

4.6: Assessment of Results and Limitations

As a way of concluding, I shall now reflect on the potential limitations of the results and interpretations presented above. The results are limited by the underlying method, which assumes that the semantic properties of words are properly encoded by the consideration of their contexts of occurrence. Linguistic theories (such as those by Harris and Firth) and examples of success in 'synonym finding' (Landauer and Dumais 2000) support this practice. Yet, this will not exhaust all semantic phenomena of words. Nor are we to assume that there is only one specific way of encoding these results. The methods include many choices that can be argued for and each of them have an impact on the results. This pluralism of acceptable methods for semantic analysis must then be combined with a general semantic pluralism, as there is no unified sense of the word's meaning and to investigate a word's meaning is to investigate one of the relevant semantic facets of the word. In the previous chapter, I have suggested to understanding the method used here as one defined in terms of subtle facets of meaning, as opposed to salient features. This means that many other forms of semantic similarity might remain outside of the scope of this method. One may very well argue via other methods (including close-reading) that other types of semantic similarity occur.

Secondly, semantic similarity has been argued to be a viable indicator of influence. Although I stand by this suggestion, at the same time I admit that semantic similarity is neither sufficient nor necessary for influence to occur. This is because not all types of intellectual influence need to exhibit themselves semantically. It is undeniable that Henry More has influenced the development of Conway's thought;

what the method does cast doubt over is that this influenced has been such as to significantly alter the broad semantic properties of her words. Conway's discourse bears more resemblance with Descartes and Hobbes despite her explicit disagreements with them. Henry More might have even functioned as a source for specific tenets of Conway's (Thomas 2018); however, the broad intellectual/semantic discourse within which she writes is not that of More. And this is a significant disconnect between the two authors, which suggests that incidental overlap of doxa should not immediately be taken as a case of influence. It does not exclude specific types of influence to still run between them – for example More's introduction of Conway to Descartes.

Do these results mean that we should not investigate Conway's overlap with Kabbalist doctrines because she did not score high in semantic similarity with that tradition? No, of course not. Nevertheless, whatever she does with this Kabbalist doctrine, we might be inclined to expect that it will be recast in a broadly mechanist, rationalist, framework. I do posit, however, that the results should warn us against characterizing her as a Quaker theologian, Cambridge Platonist, or Kabbalist. At the very least, her lack of semantic similarity with these traditions requires explanation or qualification by the scholars who place her in these traditions. Similarly, scholars who assign her to the traditions of authors that score highly should be pressed to more justification (derived from biographical circumstances, or some other sources) in support of the transmission of these ideas.

More broadly, we have seen how Cartesian semantics is used by a philosopher who tells us: "[L]et no one object that this philosophy is nothing but Cartesianism or Hobbesianism in a new guise." (Conway 1996, Chap IX/p.63). Despite Conway's creative doctrinal positions (the unity of spirit and body being the main proposal that underlies the above quote) she's still working within the broadly Cartesian program. What this clearly shows us is that conceptual similarity does not necessarily go together with doctrinal agreement. Nor, indeed, is the semantic similarity between Descartes and Hobbes to Conway particularly salient, at the very least not to Conway herself. To use the same concepts and to work within the same group of thinkers is not a question of agreeing on how the world is. It appears here more as an agreement on how to broadly make sense of the world; how do we frame the questions of natural philosophy conceptually? One can agree on this without agreeing on how one believes the world to actually be. There is an agreement on the problems, not on the solutions taken with regards to them. As Hutton formulates the issue (while holding fast to Conway's strong disagreement with Descartes): "[Conway and More participated] in an on-going philosophical debate in which Descartes set the agenda, even for his opponents." (Hutton 2004, p.52) And, for Conway, I would argue, it was Descartes who set, not just the agenda, but also the broad conceptual frame for approaching (and talking about) these topics. This also shows the power that a school of thought exudes. Even when in

stark opposition to a thinkers' beliefs, this alone is not sufficient to escape from expressing these beliefs in the terms of one's opponent. More strongly, given that the discussions of Descartes are assumed to be fruitful, and were aimed to convince Cartesians to drop their beliefs, expressing arguments *on their terms* is necessary.

In the next chapter, Descartes will personally come out as one of the most salient semantic trailblazers of the entire period, which means not only that what he did was novel, but also that he was majorly influential. Conway was one of those reached by his influence.

5: Unity through Change: Semantic Strategies

> "The capacity for radically reorienting an old language highlights one of the characteristic beauties of a new semantic picture […] Framing a new semantic picture can act as an effective filter against unhelpful inherited prejudices: we can now judge an old inferential rule or recipe solely according to its capacity to perform ably when tested against the range of settings contemplated by our new picture".
>
> (Mark Wilson, *Wandering Significance* 2006, p.551)

5.1: Introduction

Three groups of works—scholastic, Cartesian and Newtonian—proved to be semantically unified in the corpus. However, the fact that these schools were unified does not preclude their development over time. One would expect that a corpus that spans over the start of two schools (Cartesianism and Newtonianism) should show some of the changes in the vocabulary of these developing schools. Given that we find the scholastics in the corpus at the end of the apex of scholasticism, this semantic development is less obvious: "[Renaissance and Baroque Scholastics] shared a terminology, agenda, and training, and this enabled them to reach a level of detail in their discussions unparalleled in non-scholastic philosophy at the time" (Novotný 2013, p.12). A new school of natural philosophy, by contrast, will need ways to develop their semantic toolbox in order to keep up with inevitable new discoveries. While changing, they need to retain unity among their practitioners to the extent that they all still are practitioners of one and the same school.

A school of philosophy that embraces the epitaph of a "new philosophy" is likely struggling to manage the innovation within their ranks. As Stephen Menn rightfully notes, "Already in Descartes' lifetime, people were speaking of the 'new philosophy,' meaning either Descartes' philosophy or more generally the approach to nature shared by Descartes with other 'moderns'." (Menn 1998, p.18) According to del Prete (2019), the success of Cartesians to construct a unified approach that was socially stable was troubled by an amount of unclarity about what the Cartesian legacy consisted in.

In this final chapter, I will adapt and further develop a computational measure of innovativity of works of natural philosophy in order to investigate the different strategies the schools of natural philosophy employed to retain their unity and to allow

(in different amounts) for innovation. I do not assume that all thinkers within the same school are conceptually similar (which was the perspective of 'stability' in Chapter 2). Instead, I focus on 'innovativity' in order to see how certain works figure as hotspots for the innovation of important terms of the philosophical vocabulary.

A recent paper (Park *et al.* 2023) published in *Nature* investigated the disruptiveness of the sciences from 1945 to the present. The authors argue that there has been a steady decline in the average disruptiveness of papers and patents since 1945. They measure the amount of obsoletion some paper A generates. This is done by looking at how many of the papers cited by paper A are no longer being cited in later papers that also cite paper A. To see a decline in such a measure over time, they argue, is also to see a decline in the disruptiveness of science over time.

Such a measure of disruptiveness might tell us something about which works in a corpus are particularly disruptive (and perhaps, therefore, important); or, as in the above study, it might tell us something about the general trends in disruptiveness within a corpus. However, these measures of disruptiveness are citation-based and, thus, rely on two things to be applicable to a corpus of interest: (1) a sufficiently extensive and well-established citation practice in the corpus; and (2) a sufficiently encompassing citation database that describes the corpus. For the corpus under consideration in this dissertation, neither is available. Early modern authors did not have a citation practice that is comparable to our modern practices and authors were often reluctant (for various reasons) to name sources and even opponents. One potential way to go about this would be to look at other 'citation-like' databases that provide relational information about pairs of authors, such as letter databases (Kronick 2001; Sangiacomo and Beers 2020). However, although social association might be an indicator of semantic influence, as we saw in the previous chapter, it does not necessarily have to be. As such, in this chapter I introduce a semantic measure for historical corpora, one that aims to score works in a corpus by their level of innovativity based on the similarity they have to prior and future works.

I argued that three schools of philosophy formed three coherent groups within the corpus: scholastics, Cartesians and Newtonians. However, this conclusion told us nothing about individual authors and their measure of influence, nor about how these schools actually constructed and retained their semantic unity. Temporal slices could not single out disruptive works in the corpus (Gries and Hilpert 2008; 2012). Yet, one would expect, for example, for Descartes and Newton, if truly founders of their respective schools (Smith 2008; van Ruler 2019), to be particularly disruptive within the corpus. In this chapter, I thus return to the schools with a focus on finding particularly innovative works of natural philosophy. From these innovative authors and the semantic

properties of their works and general properties related to the three schools' innovation strategies, I will formulate three related semantic strategies.

Nevertheless, innovativity not only shows us something about the development in the period itself; it can additionally help us order and test the scholarship dealing with early modern natural philosophy. Using annotations of the canonicity of authors in the corpus by three domain experts, I test whether canonicity is correlated with high innovativity. The canon of the history of early modern philosophy is a debated topic, especially given the goal to include previously muffled voices in history (O'Neill 1997; Shapiro 2016).

Assuming that innovativity might be a relevant, albeit partial reason for canon inclusion and having some data on the innovativity of these historical authors, we might be able to, on the one hand, argue for the inclusion of some of the high scoring authors and, on the other hand, test the degree to which the canon agrees with my hypothesis that authors in the canon ought to be innovative in the sense defined in the chapter. There are, however, also limitations to connecting the two issues. The most important is that innovativity will partly be defined in terms of influence, so it will not be a way to recover figures that were actively repressed through history as repression exactly leads to a diminished influence.

The chapter is structured as follows. In section 5.2, I give a short overview of applications of disruption measures in scientometrics. In section 5.3, I operationalize and introduce the measure of innovativity that I use to score all the works in a corpus and describe the three sets of results I will extract using this measure. In section 5.4, I provide three result sets: average innovativity per school, the top 10 innovative authors in the corpus, and average innovativity per word. In section 5.5, I interpret the results and formulate the semantic innovation strategies as they are followed by each of the three schools. Finally, in section 5.6, I consider the scholarship and the canon by comparing canonicity with innovativity of authors.

5.2: Measures of Disruption and Innovation

Scientometrics has dealt with measures of disruption for some years (Bornmann *et al.* 2020). The idea relates to citation practices. In modern scientific practices, citations give an overview of the works that a scientific work has used in its scientific reasoning. If scientific knowledge is cumulative, one would expect that most of these articles will remain relevant even after having been cited. However, it turns out that certain works alter the face of the scientific consensus to such an extent that the references cited by the disruptive article itself are no longer relevant after the 'pivotal' paper. To model the

disruption of papers, we see how many of the papers the suggested disruptive contribution cites are no longer cited by articles that do cite the article in question. For example, paper *A* that cited papers *B*, *C* and *D* will be deemed disruptive if all other papers citing *A* no longer feel the need to cite *B*, *C* and *D* as these have been made redundant by the work done in *A*. In this way, the measure does not just tell us something about how important the article is (by counting, for example, the number of citations Nightingale and Marshall 2012) but specifically about how capable the article is in displacing research that went into it. I have now only described one specific measure (CD-index) (Park *et al.* 2023), among many others. However, all these measures generally share that they operate on the assumption that citations provide an overview of the 'input' and eventual 'output' of a piece of research. And, although within modern science this assumption needs to be at least tempered somewhat due to practices like citation gaming (Baccini *et al.* 2019), the approach appears to be proper to some extent. By contrast, this approach based on citations is not available at all for the corpus and time period I am examining. Hence, the question arises as to whether there is a way to operationalize something similar to 'disruption', but using semantic measures.

Semantic innovation has recently been approached in multiple contexts; it often uses, one way or another, semantic similarity scores as its basis. For example, in spam detection (Kumar and Bhatia 2020) or web-crawling (Mostafa *et al.* 2020), one wants to check new information for redundancy via similarity. In the case of web-crawling, new information that is to be scraped is checked for extremely high similarity with already scraped materials. If that is the case, the information can be assumed redundant or duplicate. Another way to semantically check for potentially novel research is to investigate the degree of semantic similarity between patents and research papers. Here, novelty maps not unto the semantics itself, but merely unto that research is as of yet untapped and, thus, potentially novel (Shibata *et al.* 2011).

None of these approaches, however, is exactly focused on finding works that are themselves semantically innovative in a corpus, let alone in a historical corpus. Recently though, Soni *et al.* (2020) used word embeddings to discover documents which are, in the use of certain terms, more similar to the new embedding of that term and less similar to the old embedding of that term. Additionally, by normalizing these scores per year, they can find relatively novel works for that particular year. Used on a modern corpus of scientific articles, they find that being highly cited is correlated with being semantically innovative.

As discussed in Chapter 1, the dissertation is committed to using latent semantic analysis, which means I do not use the same methods that above-mentioned authors use for the extraction of meaning. However, I will translate their general

approach (defining semantic innovation in terms of similarity with new meanings and dissimilarity with old meanings) within the semantic methods I have available. In the following section, I design a measure that builds upon Park *et al.*'s 'disruption' (2023) and Soni *et al.*'s 'innovation' (2020), but that is applicable to the corpus using the basic methods for meaning extraction used throughout this dissertation.

5.3: Operationalizing Semantic Innovativity

5.3.1 The Rationale

In the previous chapter, I leveraged techniques that allow us to gain insight into the semantic similarity of texts to investigate for a particular text (Conway's *Principles*) what other texts might have semantically influenced the author's work. Semantic similarity was taken as an indicator of influence given that the social and temporal possibility for influence occurring were accounted for. In this chapter, I will be looking at the entire Latin subcorpus without emphasizing any particular works. Thus, I cannot first say: I am interested in work x as a source, and a, b and c as drawing on x. I am just as much interested in a, b and c being sources as I am in what their sources are. A work in the corpus both plays a forward role, influencing what comes after, and is also the outcome of a history that led up to it. Especially without a more thorough vetting of possible sources as was done in the previous chapter, it is not possible to simply use semantic similarity as the decisively singular way to model semantic novelty or influence. Instead, I assume here a simplified picture, where influencing the future and breaking with the past are understood as a linear process, running from the past to the future. In such a model, two functions will be central: the continuity with the future and the continuity with the past. Then, I need a way to unify these different functions into a single measure of innovation that turns to be high when the future is similar whereas the past is dissimilar.

The idea is to first operationalize the discontinuity with the past and the future and then find a proper way to combine these two. Discontinuity with the past suggests that a work is *novel* in its application of terms, on the assumption of a simplified temporal model of semantic development. I have a body of works that could function as sources to a particular work x, but it turns out that x is generally dissimilar to all or most of them. This means that work x is introducing semantic novelties with some temporal priority. However, in this category we might also find works that are simply very dissimilar and novel, but which are never afterwards picked up and developed further. These works are then novel, but not influential.

Meanwhile, continuity with the future suggests that we have found a work with a semantic profile that is enduring throughout the corpus and, therefore, influential. According to the previous chapter, such a work is a potential source for works later in the corpus and, thus, is potentially influential. However, among these works are also works that have a similar profile to the true innovators, only say, for example, thirty years later. These capable copycats of the great innovators and their traditions are 'influential,' for in the following years their semantic profile remains operative. These works are not novel and are merely parts of large, long-running semantic profiles.

Nevertheless, the combination of these two measures can provide a method to assess the 'successful innovation', or the 'semantic disruption' I want to model. For if there are works that are both discontinuous with the past (novel) and continuous with the future (influential), we might very well have found a work in the corpus that is relatively innovative or disruptive. It is not possible to be sure that the influence is solid (perhaps work x is not itself the reason for the further continuity with the future, but actually contemporaries that have nothing to do with work x) but this case is at least an outlier. Generally, we expect that a work that has some priority in introducing semantic novelties that we then find to be enduring in the years afterward to be (partly) responsible for the success of these novelties.

Novelty and influence are here introduced as relational and temporal properties. To be influential is to have your semantic footprint occur in works after you. The same work then, of great similarity with future works in year *X* but, written fifty years later at *X*+50, would make a turnaround—it would no longer be continuous with the future (influential), it would become continuous with the past (not novel). The notions of novelty and influence here used are therefore temporal. They are also relational, in the sense that they are corpus dependent. This is partly for practical reasons (as I am in fact working with a corpus) but also partly for principled reasons. A work that is simply very dissimilar to all other works in the corpus will be scored as particularly novel (for it is also dissimilar to its past). A work that is simply very similar to all other works in the corpus will be scored as particularly influential (for it is also similar to its future). Yet, neither of these works will come out as particularly innovative: they are not more similar to their pasts relative to their similarity to their futures nor the other way around. Therefore, a work that simply should not have entered a corpus (due to mistakes in the latter's construction) will be singled out as particularly innovative. For example, Descartes might be expected to be influential in a corpus of early modern natural philosophy, but, within a corpus of legal documents, Descartes' works should not turn out to be innovative, they will show up as mere aberrations.

5.3.2: Methodology

Given the above rationale for the measure, our first task should be to quantify the continuity with the past and the future of a certain work within a corpus of texts. To do so, I will use the same semantic measures that have been introduced in Chapter 1 and were used in the previous chapters. These techniques will provide us with the way to measure the level of continuity with either the past or the future. In addition, I also need a way to define the past and future of a particular work. For starters, let us simply take all the works published before the work in question as past and all the works published later as future. An average of all the individual similarity values with all past works and with all future works will give us two average values: continuity with the past and continuity with the future. The model results into two formulas, where X is some work that we want to derive scores for, N the number of works (published either before or after the work in this corpus), and Sim(x,y) the similarity function based on cosine similarity as detailed in Chapter 1:

$$Continuity\ with\ the\ Past\ (X)\ [CwP(X)] = \left(\sum_{i=\ first\ work\ in\ corpus}^{Publication\ date\ X} Sim(work_i, X) \right) \Big/ N_{before}$$

Equation 5.1: Definition continuity with the past (CwP)

$$Continuity\ with\ the\ Future\ (X)\ [CwF(X)] = \left(\sum_{i=\ Publication\ date\ X}^{Last\ work\ in\ the\ corpus} Sim(work_i, X) \right) \Big/ N_{after}$$

Equation 5.2: Definition continuity with the future (CwF).

Now, as we have seen before, the similarity here is defined on a per word basis. Therefore, the above formula will only consider the continuity of X with the past and future in the corpus on the basis of a singular word. To generalize these results, I make use of a multitude of important concepts in early modern natural philosophy and take the average CwP and CwF values X gets for these different terms.

However, this naïve approach leaves us with a gap in the results: what do we do with works that are contemporaneous with the work we are investigating? They are neither past nor future. Additionally, what to think of works published only, one or two years apart, for instance? I suggest that they are so close to each other that they might

be taken, for all intents and purposes, to be contemporaneous. This means another parameter is needed for 'contemporaneous', which stands for the minimal temporal distance I shall accept between works, outside which they do not count as contemporaneous anymore. In the present research, a 'contemporaneous' value of two years will be used.

With these additions, there is an algorithm that provides us with two scores, the continuity with the past and future of a work in the corpus, for multiple different word-types. This process can of course then be repeated for multiple works in the corpus, to find the CwP and CwF values for each work, for the entire corpus.

These values might be of interest on their own, but, as discussed above, the interest is for works that have a low average similarity (discontinuity) with the past and a high average similarity (continuity) with the future. At this point, we need a way to extract an 'innovation' value, that incorporates both scores. Since both values are based on similar methods (cosine similarity), it is only on different sets of data (past and future parts of the corpus) that the values are comparable. For instance, a work that has a CwP value that is twice as large as its CwF value, is indeed twice as continuous with the past as it is with the future. Let us make use of this useful property by defining the 'innovation' value by means of a ratio. By dividing the CwF by the CwP, one gets a value that is >1 when the continuity with the future is greater than with the past, between 0 and 1 when the continuity with the past is greater than with the future, and exactly 1 when they are equal. This means that a score of 2 signifies that the continuity with the future is twice as large as with the past and 0.5 signifies the inverse. The result is:

$$Innovativity(X) = {CwF(X)}\Big/{CwP(X)}$$

Equation 5.3: Naïve definition innovativity.

However useful for interpretation (0.5 being the inverse of 2, 0.33 of 3, etc.), the numbers extracted here are impractical for later calculations of averages of innovativity scores. The average of 0.5 and 2 is in fact (2 + 0.5)/2 = 1.25, while in the interpretation the 'weight' of a 0.5 is as much as 2 (since 0.5 signifies being twice as continuous with the past than with the future and 2 signifies being twice as continuous with the future as with the past). We would, thus, like a score of 0.5 and 2 to average out to 1, not something above or below 1. To amend this, a score of 0.5 should be interpreted as weighing as heavily as a score of 2, but in the opposite direction. This is done by inverting the values between 0 and 1. Since, 1/0.5 = 2. Finally, this should be a negative value as it should be the inverse of 2. So, one gets that a score of 2 and of 0.5 get transformed into a score of 2 and -2. Finally, take 0 as our turning point for ease of reading the results,

this is achieved by adding 1 to the negative values and subtract one from the positive values. All positive values now signify more continuity with future than past, and negative less continuity.

$$Innovativity(X) = \begin{cases} \left(\frac{CwF(X)}{CwP(X)}\right) - 1, & \frac{CwF(X)}{CwP(X)} \geq 1 \\ \left(-1/\left(\frac{CwF(X)}{CwP(X)}\right)\right) + 1, & \frac{CwF(X)}{CwP(X)} < 1 \end{cases}$$

Equation 5.4: Adjusted definition innovativity.

As an example, if one has $\left(\frac{CwF(X)}{CwP(X)}\right)$ = 1, a score of 0 is obtained, if 0.333, we get (-1/0.333) + 1 = -2, and if 3, we find a final value of 2.

I thus extract the innovation scores for multiple words in a singular work in the corpus. I then repeat the process for every work in the corpus and I thus obtain a measure of the innovativity of each work in the corpus. It is these scores that will function as the main results that will be investigated in the rest of the chapter.

However, there are three remaining restrictions that need to be considered in regards to this method. First, in order to have somewhat stable results the work investigated needs to be compared to a sufficient number of other works. Nevertheless, works very early in the corpus or late in the corpus will get CwP or CwF scores that are based on a very small sample. Even worse, the first and last work will not even have a defined past and future. This means that for the following investigations we should not calculate an innovation score for first and final few works in the corpus, while of course still using these works as past and future works for the scores of the rest of the works in the corpus. In this study I exclude the first and final 30 works. Second, works by the same author tend to be semantically similar to each other. This means that early works of an author tend to be seen as innovative by the algorithm, as it now seems that the author is predicting the coming of later works with a similar semantic profile. Meanwhile, later works are scored as less innovative, as the works have close counterparts in their past. This is not a behavior we want and, thus, works by the same author are not taken into account in the calculation of the CwF and CwP values.

The final issue has to do with the assumption that language evolves over time, irrespective of the particularities of certain topics of investigation and authors. And, since the corpus is of finite length, later works (for example those published in 1750) will have a 'future' that is defined by works spread over 50 years and a past that is defined by works spread over 150 years. This means that it should be expected in such a case that later works will generally be scored more innovatively, since their dissimilarity to

the past is more easily attained than that it is for a work from 1650. Initial results showed this–a linear positive bias based on year of publication was found. To remedy this shortcoming, it made sense to define a more limited window of time, outside of which would not be taken along in the definition of the past or future of a work. The window chosen is 130 years; it is by using such a window that the results turn out to have no structural bias in favor of either earlier or later works.

5.3.3: Experiment Set-Up

I examine the same terms I used in Chapter 2 for the investigation of the Latin works there: '*corpus,*' '*pars,*' '*motus,*' '*ratio,*' '*moveo,*' '*aqua,*' '*locus,*' '*tempus,*' '*ignis,*' '*terra,*' '*radius,*' '*deus,*' '*species,*' '*forma,*' '*materia,*' '*homo,*' '*anima,*' '*causa,*' '*potentia,*' '*genus*' and '*natura*', as these resulted from independent topic modelling experiments carried out on the corpus as central terms. Similar to the stability scores, the aggregated innovativity scores will be generated from the scores for each of these words. This means that the innovativity scores should be read as scores relative to this selection of terms. However, as argued in Chapter 2, this collection did not show such a wide spread of scores that aggregation could not be expected to give us an accurate average score. Additionally, I use the Latin-language sub-corpus, since this is the largest monolingual corpus in the total multilingual corpus with the most substantial annotation set of school affiliation. It follows that the developments I sketch here are restricted to the Latin language. Developments in English at British universities and in French in French universities are not considered here for practical purposes. Thus, some Newtonian and Cartesian developments of terminology will not be investigated as these will have occurred in the vernacular.

From the innovativity scores (which are defined per work and per word), three inspectable datasets will be extracted. Firstly, using the same annotations as in Chapter 2, I investigate the innovativeness of all scholastic, Cartesian and Newtonian works aggregated into their school score. This will be done for all terms averaged and per term. The hypothesis here is that, given that there are many scholastics early in the corpus and that scholastics will have continuity mostly with other scholastics (which I assume on the grounds of the results in Chapter 2) and discontinuity with Newtonians (more often occurring later in the corpus), scholastics will on average have a high continuity with the past and low continuity with the future and, thus, a low average innovativity. The Newtonian dissimilarity with much of the early scholastic works will instead suggest a high dissimilarity with the past and, thus, high innovativity. Secondly, I extract the top-10 innovative works in the corpus. These will be analyzed individually and by considering their school affiliation. I will compare them in particular on the grounds of the terms with respect to which they innovate on and check for expected innovators. Here,

Newtonians stand out and suggest their 'masked' approach to semantic innovation, which involves public avowals of conservatism combined with extensive conceptual development and innovativeness. Finally, I produce the average innovation scores of each of the investigated terms, which will be examined and compared with the earlier found stability scores of Chapter 2; mathematical terms stand out as predilect topics of innovation.

5.4: Results

First, in Table 5.1, I present the average innovativity scores of the different schools of natural philosophy (derived by averaging all authors' personal innovativity scores):

Scholastics	**Cartesians**	**Newtonians**
-0.055	-0.009	0.060

Table 5.1: Average innovativity scores of scholastic, Cartesian and Newtonian authors.

As I had already shortly argued above, the ordering of average innovativity agrees with the expectations. Since scholastics, Cartesians and Newtonians have high same-school similarities and low cross-school similarities and scholastics are more heavily represented early in the corpus, while Newtonians appear later in the corpus, we should expect Newtonians to be scored on average more innovatively than scholastics. This is because a later scholastic author will be highly similar to the past (more heavily populated by fellow scholastics) and highly dissimilar to the future (more densely populated by Newtonians). However, this general trend is seen here even stronger. Scholastic authors are generally negatively innovative (more continuous with their past than their future), to the extent that *every* annotated scholastic in the corpus had a negative innovativity score, including the early works. This means that the semantic innovations of the scholastics hardly get picked up in early modern natural philosophy or are hardly ever introduced. Cartesians show a more mixed picture (including a very innovative Descartes himself, which will be detailed in the next set of results), while Newtonians have a generally (though not univocal) higher innovativity score.

It follows that the question as to how scholastics remain unified despite their conceptual innovation is somewhat moot since their unity derives already from a lack of semantic innovation within natural philosophy. This might have been expected given that some of the subschools I identified in Chapter 2 explicitly refer to older sources; Aristotle, Aquinas, Scotus. That is not to say there might not be valuable doctrinal innovations being developed (as we saw in previous chapter, semantic and doctrinal innovation are not tied together), but semantically the scholastic school appears not to be particularly innovative. In the meantime, the question reasserts itself for the "New

Philosophy": given semantic innovation, how could the schools retain a sense of unity? To see this more clearly, we need more fine-grained ways of looking at the innovativity scores. Since the score is defined per work, I extract the top-10 most innovative works in the corpus:

RANK	NAME	YEAR	TITLE	SCORE
1	Willem 's Gravesande	1723	*Philosophiae Newtonianae*	0.1858
2	Willem 's Gravesande	1720	*Physices elementa mathematica […] sive introductio ad philosophiam Newtonianam*	0.1436
3	Georg Hamberger	1741	*Elementa physices methodo mathematica*	0.1410
4	Rene Descartes	1644	*Principia philosophiae*	0.1395
5	Johann Bernoulli	1742	*Opera omnia*	0.1257
6	Pieter van Musschenbroek	1734	*Institutiones physicae*	0.1152
7	Pieter van Musschenbroek	1726	*Elementa physico-mathematica*	0.1127
8	Johan Keill	1701	*Introductio ad veram physicam*	0.1018
9	Pieter van Musschenbroek	1726	*Epitome elementorum physico mathematicorum*	0.0896
10	Isaac Newton	1687	*Philosophiæ naturalis principia mathematica*	0.0880

Table 5.2: Top-10 works ordered by innovation score within the corpus.

A few observations about these results are in order at this point. Perhaps unsurprisingly, Descartes' *Principia,* which will function as the inspiration for many following 'Cartesian' authors, features among the ten most innovative works. However, given the lower average score of Cartesian innovativity, his inclusion shows how exceptionally disruptive this work has been semantically. Similarly unsurprising is Newton's *Principia Mathematica*, which will give rise to a large group of following 'Newtonians'. This corroborates a hypothesis presented in Chapter 2: although temporal slices based on the publications dates of these authors' works did not work, we do in fact now find that these works were particularly novel and influential in this corpus of early modern natural philosophy. It also suggests that canonical authors in the corpus might be generally innovative, which would accord with Soni *et al*'s (2020) finding that semantic innovativity correlates with successful scientific activity measured through citations.

However, this symmetry between Newton and Descartes does not run all the way. None of the other entries, besides Descartes himself, are by authors of a broadly Cartesian persuasion (except for perhaps Hamberger, on whom I will dwell more later). By contrast, we find in the top-10 no less than six other entries by authors who can be clearly characterized as Newtonians themselves. These are Pieter van Musschenbroek (1692 – 1761, 3 entries), Willem ‘s Gravesande (1688 – 1742, 2 entries) and Johan Keill (1671 – 1721, 1 entry). The first two are known as (self-professed) popularizers of Newtonian philosophy, introducing it to the continent and to the Netherlands in particular by reworking Newtonian philosophy into textbook form (Lind 1992; Besouw 2017; Present 2019).

Keill, meanwhile, was not based on the continent but in Britain, and was an early champion of Newtonian philosophy. These results suggest that the two authors were not only successful (a high similarity with authors who come later) but also not completely similar to what came before (including earlier Newtonians). If this is so, then ‘s Gravesande, van Musschenbroek and Keill successfully ‘translated’ Newtonianism in such a way that subsequent authors could work with their analyses, without necessarily needing to return to the language of Newton himself in all respects, who was from some point onwards more often referenced than properly read (Lind 1992, p.146).

Both Newtonians and Cartesians show similarities to how Kuhn described paradigms: after the introduction of a paradigm (by a founder), a school is formed around this paradigm, within which thinkers improve and investigate (Kuhn 1962). However, there is also a difference between Newtonians and Cartesians. Although Descartes himself is taken up by many people after him, none of his own followers had a similarly large semantic impact on natural philosophy. In this way, only Descartes makes it among the most semantically innovative works, as the founder of a school of natural philosophy that would for a century speak in ways laid down by Descartes, and not in ways laid down by other intermediate developers of their philosophical language. Meanwhile, Newtonianism continues improving and working on the philosophical vocabulary, allowing multiple major innovators within their ranks. Newtonianism grouped itself around Newton in name, but, in reality, the following Newtonians, either champions or popularizers, sharpened the semantic profile and, thus, were themselves of major import in the development of the school. This is also in line with the high average Newtonian innovativity score found above.

Two authors require further explanation however: Georg Erhard Hamberger (1697-1755) and Johann Bernoulli (1667 - 1748). Johann Bernoulli was a Swiss mathematician, who is not usually discussed in the context of the history of philosophy. However, he has some exchanges with Leibniz and was embroiled in the Newton-Leibniz

priority dispute. Georg Hamberger, professor in Jena, is generally a seldom discussed figure. However, he is described by Gunter Lind as a central figure in the move from mechanistic accounts of physics to those that incorporate Newtonian ideas in the German context:

> The third phase of the mechanistic textbook tradition was shaped by the continued work on Wollf's and G.E. Hamberger's systems by their students and followers. The debate with Newtonian physics and the rivalry with the successful Newtonian textbooks plays a special role in this development. (Lind 1992, p.124, translation mine)[37]

Hamberger himself resists interacting extensively with Newtonianism, but his thought will soon be compared and contrasted to the Newtonian program by his followers. In this way, together with Descartes, Hamberger's work shows itself as the only decidedly non-Newtonian entry in the top 10.

Additionally, Hamberger's and Bernoulli's works accord with a number of other works in the top 10; Bernoulli the mathematician's collected works and Hamberger's *Elementa Physices Methodo Mathematica* agree with other similarly mathematizing works like *Physices elementa mathematica* (#2) *Elementa physico-mathematica* (#7), *Epitome Elementorum Physico Mathematicorum* (#9) and *Philosophiae Naturalis Principia Mathematica* (#10). These works are all explicitly themed *mathematical physics*. This can be seen as writing in line with Newton's work. In this period mathematical physics develops its technical apparatus and sharpens its terminology. Additionally, we find in Bernoulli at least 50 references to Newton, whereas only five in Hamberger's work, further cementing Lind's characterization of Hamberger as decidedly mechanistic. Hamberger's innovativity appears to derive from being an influential "in-between" physical theory that would later allow for Newtonian influences. Even though Bernoulli is not explicitly labeled as Newtonian, he is active in a somewhat similar program of mathematizing physics. We see the interest in innovating and developing certain kinds of terms by looking at these author's word-indexed innovation scores in Table 5.3:

[37] Original: „Die dritte Phase der mechanistischen Lehrbuchtradition wird durch die Weiterarbeit an den Systemen Wollfs und G.E. Hambergers durch deren Schüler und Nachfolger geprägt. Eine besondere Rolle spielt dabei die Auseinandersetzung mit der newtonischen Physik und die Konkurrenz zu den erfolgreichen newtonischen Lehrbüchern."

WORD	1644 DESC	1687 NEW	1701 KEILL	1720 GRA	1723 GRA	1726 MUS	1726 MUS	1734 MUS	1741 HAM	1742 BER
Anima	-0.017	N/a	N/a	N/a	N/a	N/a	N/a	-0.578	N/a	N/a
Aqua	0.059	-0.106	0.020	0.098	0.115	0.122	0.017	0.186	0.222	0.088
Causa	0.120	0.087	0.081	0.090	0.067	0.079	0.053	0.014	0.077	0.026
Corpus	0.253	0.267	0.203	0.204	0.299	0.170	0.158	0.215	0.256	0.184
Deus	0.203	0.041	0.032	0.057	0.047	-0.069	0.008	-0.072	0.049	0.148
Forma	0.023	-0.088	-0.029	N/a	-0.051	0.011	0.034	0.138	0.160	0.009
genus	0.018	0.123	0.094	0.162	0.210	0.104	0.105	0.089	0.141	0.054
homo	0.052	N/a	0.210	0.203	0.203	0.047	0.154	0.144	0.154	0.085
ignis	0.139	N/a	-0.042	-0.047	0.024	-0.005	-0.053	0.0635	0.134	-0.028
locus	0.234	0.030	-0.016	0.064	0.145	0.076	0.039	0.111	0.141	0.110
materia	0.243	0.069	0.042	-0.058	-0.016	0.002	0.011	0.063	0.086	0.026
motus	0.295	0.151	0.114	0.147	0.222	0.179	0.099	0.203	0.209	0.145
moveo	0.255	0.058	0.043	0.121	0.142	0.111	0.044	0.137	0.112	0.173
natura	0.191	0.075	0.091	N/a	0.066	0.121	0.113	0.135	0.023	0.135
pars	0.219	0.099	0.056	0.125	0.168	0.114	0.026	0.143	0.173	0.089
potentia	0.021	-0.112	0.363	0.102	0.797	0.250	0.261	0.326	N/a	0.218
radius	0.177	0.258	0.138	0.432	0.530	0.299	0.193	0.394	0.272	0.593
ratio	0.105	0.294	0.277	0.408	0.491	0.414	0.480	0.386	0.251	0.310
species	-0.040	-0.076	-0.014	N/a	-0.187	-0.156	-0.133	-0.057	-0.117	-0.104
tempus	0.096	0.377	0.312	0.310	0.425	0.344	0.220	0.361	0.102	0.050
terra	0.281	0.037	0.062	0.024	0.018	0.039	-0.037	0.017	0.141	0.126

Table 5.3: Innovation scores per word-type for the top-10 innovative authors

Looking at the results, a number of interesting things occur. Firstly, several particularly high scores show that there is a group of authors all innovating with regards to the words '*potentia*', '*radius*', '*ratio*' and '*tempus*'. What is interesting is that this group is a group of Newtonian authors (Newton, Keill, s' Gravesande twice and van Musschenbroek twice). All of these authors wrote textbooks that rework and introduce Newtonian philosophy. This does not necessarily tell us that the works are similar in their use of these terms. In fact, they are all innovative with regards to similar words. Comparing this list of words to Descartes, we find that, for Descartes, '*tempus*', '*potentia*' and '*ratio*' are not clearly topics of innovation. Instead, Descartes introduces enduring novelties in the use of words like '*locus*', '*moveo*', '*natura*', '*pars*' and '*deus*'. This tells us two things; not only are Newtonians semantically similar, they are also similar in the terms they tend to innovate upon. Meanwhile, Descartes innovates on very different kinds of terms.

So far, my suggestion has been that many of the works can be seen to innovate on similar terms, refining and continuing on a broadly Newtonian trend, that is being reworked through popularizers, mathematicians and champions. Descartes meanwhile seems to jump out as an outlier. By checking the pairwise average similarity of the innovation vectors I derive a ranking of which authors are most similar to the other nine in the types of words they innovate over:

DESCARTES, Principia philosophiae (1644)	0.580138
HAMBERGER, Elementa physices methodo mathematica (1741)	0.671873
NEWTON, Philosophiæ naturalis principia mathematica (1687)	0.686495
KEILL, Introductio ad veram physicam (1701)	0.738951
BERNOULLI, Opera omnia (1742)	0.755832
MUSSCHENBROEK, Epitome elementorum (1726)	0.763508
GRAVESANDE, Philosophiae Newtonianae (1723)	0.775287
GRAVESANDE, Physices elementa mathematica (1720)	0.79658
MUSSCHENBROEK, Institutiones physicae (1734)	0.820349
MUSSCHENBROEK, Elementa physico-mathematica (1726)	0.829117

Table 5.4: Average pairwise similarity of top-10 authors to each other of their innovation vectors.

We notice that Descartes is the odd one out. Descartes is the least similar with respect to which words he innovates on compared to the other nine authors. As we saw in Table 5.3, words like '*deus*', '*locus*', '*materia*' and '*moveo*' which will not be innovated on further much, are all major factors in Descartes' high innovation vector. Additionally, the one other author that I argued does not fit the label Newtonian is Hamberger, the author secondly most dissimilar to all the others in terms of innovation vector.

Concerning then the two schools that we concluded to be innovating successfully, Cartesians and Newtonians, we find an indication that Newtonians tend to innovate on the same terms. The semantic differences between different generations of Newtonians appear to consist in the conceptual drift of the same words.

Now, to finalize this result set, let us look at the average innovativity of specific words across the entire corpus, showing us which words are innovated heavily upon:

radius	0.053443	causa	0.002758
motus	0.04175	locus	-0.0017
tempus	0.029305	**average**	-0.02556
ratio	0.024223	moveo	-0.0283
natura	0.020852	ignis	-0.03322
corpus	0.020731	aqua	-0.04511
homo	0.015534	materia	-0.07779
genus	0.012723	species	-0.10864
pars	0.012289	potentia	-0.1216
deus	0.008619	forma	-0.18117
terra	0.008577	anima	-0.2896

Table 5.5: Word-type based average levels of innovation

Not all word-types are equal in the average innovation, I found. However, the spread of their scores is lower than for the individual works (where we have average scores ranging from 0.186 (‘s Gravensande) to -0.347 (Koendig). This means words are less differentiated in their average innovation than works. This observation makes sense since each word is used all over the timeline and we should not expect a word that is being innovated in a particular period to also be innovated in every other.

However, we can still interpret these results. We find high average innovation scores for the mathematical terms (‘*radius*’ and ‘*ratio*’). This is most likely because new and more standardized uses are found and continuously developed. Similarly, we find the core terms of mechanicism ‘*corpus*’ and ‘*motus*’ among the most highly innovated words in the corpus. ‘*Tempus*’ is also innovated on, although a quick look at the full list of results suggests that the positive scores start occurring from 1687 onwards (i.e., with the advent of Newtonianism). We can check this by comparing the average score before 1687 and afterwards, in which case we find a big difference: the average innovation before 1687 is 0.008 and after 1687 is 0.059. Note that the innovation after 1687 of ‘*tempus*’ would catapult it to the most innovative term of the corpus–a core topic of innovation, thus, for the Newtonian school.

At the lower end, we find scholastic terms dominating: '*anima*', '*forma*', '*potentia*' and 'species'. This is not unexpected: if these words remain as they are, they will simply be used less by the non-scholastic authors, while remaining stagnant for the scholastic authors. It also suggests that, although we find scholastic authors operating all throughout the eighteenth century in significant numbers, they did not semantically innovate on their terminology to the extent that Cartesians and Newtonians did.

5.5: Semantic Strategies for Combining Stability and Innovativity

Scientists need each other in order to build on each other's ideas. Some of the major theories about scientific development depend on different ways in which social and linguistic unity is asserted. A group needs some stable programmatic core around which to order their activities. This is particularly difficult in contexts in which knowledge is generated, i.e., scientific contexts. On the one hand, a group of thinkers wants to be able to say that they improve on knowledge, find out new things and make sense of the world. At the same time, they need and claim continuity with the past and with their peers. The results presented in the previous sections provide the basis to categorize the three schools in how they differently deal with semantic innovation among themselves, despite the goal of being coherent as a stable school. Scholastics (within this corpus) do not innovate semantically. Cartesians do so to some extent, but are unable to assert a research program that builds on itself, while the Newtonians innovate while masking their activities.

Since I have found that the scholastics within this corpus are not semantically innovative, their semantic strategy appears to be one of not maximizing semantic innovation. That is of course not to say that these works do not innovate in other ways. For one, as we have seen in Chapter 4, the authors might be very different with regards to doctrinal positions even when being semantically proximate (like Descartes and Conway).[38] Late scholastics allow themselves to resolve the tension by approaching the language in which they speak as something that can be kept stable over time. Meaning ought not to change, only philosophical positions using scholastic language can. Whereas Newtonians and Cartesians will be somewhat reluctant to refer back to older

[38] In particular, Jesuits introduced novelties although they were working within the scholastic framework and in spite of repressive tendencies from higher-ups, forcing them to employ tactics that angered superiors: "Nor was the General pleased with the increasing penchant to cite a passage from Aquinas, as if adhering to his doctrine, while otherwise belying it." (Feingold 2003, p.19) However, these hard-fought novelties, where semantic, were not enough to generally produce a positive innovativity score for the scholastic school.

sources, scholastics are generally inclined to refer, cite and consider earlier positions and approaches from their own school:

> Modern non-scholastic philosophers developed their views with little regard for what the larger philosophical community thought and wrote; their argumentation took into account views of only a handful of authors. […] In contrast, scholastic philosophers (both Renaissance and Baroque) took into account a large number of works, arguments, and positions; their aim was usually to classify and present all possible answers to a question before answering it in their own way. […] The scholastics— in contrast to modern individualists— regarded themselves as workers in a large network. (Novotný 2013, p.12)

The scholastic semantic strategy is to attain linguistic and social unity through rejecting innovation and disruption and, instead, choosing conservation, completeness and continuity.

Descartes introduced his philosophy as a 'New Philosophy'. The New Philosophy was, as such, a default way to understand Cartesian practice as revolutionary and not held back by traditions. Instead of piecemeal and sluggish construction, Descartes tells us:

> […T]hings made up of different elements and produced by the hands of several master craftsmen are often less perfect than those on which only one person has worked. […] This is also the case with those ancient cities, that in the beginning were no more than villages and have become, through the passage of time, great conurbations; […] they look more like the product of chance than of the will of men applying their reason. And if one considers further that there have always been officials whose task it was to ensure that the design of private buildings should contribute to the beauty of the town as a whole, it will become clear how difficult it is to carry anything through to completion when working only with what others have produced. (Descartes 2006, p.12)

This is an extremely effective way of positioning oneself. If one works on what came before one gets limited and weighed down by past, sluggish, ingrained mechanisms. Instead, the new is fresh and provides the freedom to move in the directions that thought requires, like an architect who freely designs buildings and cities. As the results showed us, Descartes successfully kickstarted a group of thinkers that followed his new semantic profile. Not all Cartesians were in favor of this revolutionary self-styling. Attempts to interpret Descartes as essentially espousing Augustinian doctrines were suggested and attempted, despite Descartes' own resistance to this connection

(Schmaltz 2016, Ch.3). Although the New Philosophy would not be the sole way of understanding Cartesian philosophy, it remained true, especially in the early periods of Cartesianism, that it was aimed at an overturning of tradition and authority. As Roger Ariew observes, "An important aspect of this engagement [in a dialogue with Descartes' contemporaries] concerns his endeavor to establish Cartesian philosophy in the Schools; that is, to replace Aristotle as the authority there." (Ariew 2014, ix) However, after Descartes' major impact on thinkers after him, no other Cartesians would be similarly innovative and influential in the Latin language, nor would there be a visible sense of semantically 'progressing' internally to the school: Cartesians did not coalesce into a coherently semantically developing school.

To understand oneself as operating within a "new philosophy" creates a tension with the possibility of continuing to work on others' innovations. Instead, followers of Descartes will extensively rework Cartesian idea and position themselves as the true disciples of Descartes to the exclusion of others. The school, in turn, becomes unable to attain agreement on what the right way to take Cartesianism, is. (del Prete 2019)

The semantic strategy of Cartesians is not one that successfully enforces a research program. Instead, they innovate freely based on the semantic basis Descartes laid down. This provides some explanation for the high stability of the Cartesian school we found in Chapter 2: they do not appear to continue to successfully develop their system, but are all directly relating and innovating on Descartes himself. This agrees with Tad Schmaltz' understanding of Cartesianism as a "biological species". The only thing that truly unifies all Cartesians is that they trace their origin to Descartes. But neither essences nor selection mechanisms to retain unity within the groups of descendants of Descartes are available, leading to a proliferation of varied Cartesianisms, and no coherent research program (Schamltz 2016, Intro).

This would also give some explanation for the lower innovativity score of Cartesians than the one we found for Newtonians: without continuing on each other's terms in a coherent research program, Cartesians that follow Descartes cannot exert influence onto the future. The unity of Cartesians remains in tension with their understanding of themselves as novel thinkers, not restricted by structures of tradition and institutions, and unified only by their shared origin.

With Newtonians, we find the best represented group in the top 10 semantically innovative authors in the corpus. But the people we find here are somewhat surprising, for besides (and above) Newton, we find Newtonians that are in secondary literature best known as popularizers (and not innovators), such as van Musschenbroek and s' Gravesande or champions, like Keill. I found that these

Newtonian trailblazers all tend to innovate on the same terms. Van Musschenbroek and ‘s Gravesande are best known as popularizers of Newtonian philosophy; Keill as a champion and defender. It might appear as unexpected that these three authors innovated the semantic profile of early modern natural philosophy significantly, to an even greater degree than Newton. For Newton was for Newtonians the great authority to refer to.

Despite these works being as similarly innovative as Newton’s, they still defer to his authority. How then can it be that the Newtonians who are so vocal in their conservativeness also come out as semantic trailblazers? I suggest that this is an important move toward a successful semantic strategy for a group of thinkers. These authors mask their innovation and openly claim that they are close to Newton. But at the same time, they innovate in a way that gets picked up on later. To check these authors’ relation to Newton, let’s see how Newton’s 26 highest similarity scores look like with authors who publish after he did:

1688GEULINCX	**1688LANGENHERT**	**1701KEILL**	**1702GREGORY**	**1716HERMANN**
303.125	303.75	437.1176	382.5882	354.9412
1720GRAVESANDE	**1722SERRURIER**	**1726MUSSCHENBROEK**	**1726MUSSCHENBROEKPhysicoMathematicorum**	**1732JURIN**
341.5714	304.8235	311.5294	335.8235	310.1333
1734GRAVESANDE	**1742BERNOULLI**	**1748MUSSCHENBROEK**	**1752KANIGSEGG**	**1755REDLHAMER**
307.2	331.3529	315.5882	304.8889	318.7059
1757DeLaCAILLE	**1760SIGORGNE**	**1769ZALLINGER**	**1770BURKHAUSER**	**1771SEGUY**
343.2	371.2667	376.7059	316.9375	319.7647
1772ZALLINGER	**1774REICHENBERGER**	**1774ZALLINGER**	**1775BRUCHAUSEN**	**1776MATHES**
302.5	305.6923	337	334.0588	307
1786SWINDEN				
315.25				

Table 5.6: Works with similarity over 300 with Newton’s *Principiae*

Keill is both one of the earliest highly similar works and also the most similar overall to Newton. Keill thus has the advantage that whether his profile or Newton’s profile is influential, in both cases, he will be scored as an influential author. This incurs the suspicion that Keill was innovative because he would do exactly what Newton was doing very soon after Newton did it. Given this similarity, Keill appears as an early adopter of

Newtonian language in the corpus and, as such, as innovative simply for being "like Newton" at a time that Newton himself was also innovative.

The same cannot be said, however, for s' Gravesande and van Musschenbroek. These two authors are already less distinctly (although still highly) similar to Newton himself. They were also active quite some time later. This means that these authors are not merely very early adopters successfully imitating Newton. Nevertheless, as pointed out earlier, they do agree with the other Newtonians about which terms are the ones that should be innovated upon. Mathematical terms like 'radius' or 'ratio' or terms central to the Newtonian approach to physics (such as 'tempus'), are topics of innovation that remain stably the focus of innovation across multiple major Newtonian works. First, this overturns the idea that 's Gravesande and van Musschenbroek are best understood as merely conservatively introducing Newtonian thought to a new public. Their not overly high similarity to Newton (like Keill's) means that they are semantically different from Newton to some extent. Their similarity with works that are published later (more so than Newton) also suggests that Newton's thought was not just transferred but also transformed in passing through 's Gravesande's and van Musschenbroek's thinking. How can we account for them being so well-known as Newtonian popularizers?

It appears that major Newtonian innovators mask their innovation by very explicitly agreeing with Newton and downplaying their own addition. This mimics what I have called 'façade' behavior in Chapter 3: very visible similarity but understated and hidden dissimilarity. I opt for the term 'masking' to describe the behavior here, since façade behavior was introduced to capture the unaware dissimilarities that occur. In other words, façade behavior captures when authors believe themselves to be in agreement semantically, but, make use of hidden subtleties that elude them. Masking, meanwhile, describes behavior where the authors were to some extent aware of the underlying dissimilarity, but actively seek to belie that fact. I take the Newtonian innovators to be closer to masking than to façade behavior.

Recent works on both 's Gravesande and van Musschenbroek has argued that there was a measure of rhetoric to their avowals as Newtonians and in general that these authors should be rehabilitated as innovative thinkers. As Jip van Besouw tells us about 's Gravesande, the prevailing understanding of 's Gravesande as a Newtonian should both be challenged and yet understood as instigated by 's Gravesande himself:

> […T]here are important pitfalls in regarding 's Gravesande as a Newtonian. A first problem is that those who have argued for classifying him as a follower of Newton have almost without exception done so from 's Gravesande's own

> perspective. More specifically, historians and philosophers have taken him at his word for following the methods of Newton. (van Besouw 2017, p.8)

And as Pieter Present tells us of van Musschenbroek, his self-fashioning as a 'simple' Newtonian was aimed at underwriting the image of Newtonianism as a school characterized by a lack of controversy:

> Reading van Musschenbroek's rhetoric, we saw how he took rhetorical advantage of this criticism and consistently tried to show how (Newtonian) experimental philosophy succeeded where Cartesian philosophy had failed. Van Musschenbroek presented experimental philosophy as an enterprise built upon a stable foundation of observations and experiments, and the community of experimental philosophers as characterised by harmony and consensus. (Present 2019, p.42)

Both of these scholars have recently insisted on the unorthodox use that van Musschenbroek and 's Gravesande made of the Newtonian framework. Rather than being just popularizers, these two thinkers introduce substantial philosophical innovations. This much is shown by the results as well, and this recent work is in agreement with van Musschenbroek's and 's Gravesande's high innovativity scores. However, although I agree that it is sensible to see beyond their self-styling as Newtonians, the rhetoric was an important part of the way a broadly Newtonian approach to natural philosophy could flourish. Because it is exactly by partly masking their innovativity that a social unity within the school could be maintained despite allowing for the necessary semantic innovations. Others who then take over from these innovators might 'skip' their direct influences and instead retrace their influence to Newton despite their higher similarity to van Musschenbroek or 's Gravesande.

A final similarity among these Newtonian innovators is their social position. Whereas Descartes and, with him, many Cartesians often operated outside of the university contexts and were in competition with each other for recognition (except for small success in the Netherlands and a somewhat more strong presence in France) (Schmaltz 2016, Intro), Newtonians usually operated within the university context, Newton himself being very active and successful in appointing followers of his philosophy to various chairs (Shapiro 1971, p.71). Major Cartesians authors like Jacques Rohault (1618 – 1672) and Pierre-Sylvain Régis (1632 - 1707) worked through popular lectures that sometimes led, according to J.L. Heilbron to "care more for the phenomena than for the system, not metaphysics but clarity, eloquence and manipulative skill, brought in auditors." (Heilbron 1979, p.158)

The potential impact of university position is exhibited by the most successfully innovative works in the corpus. These are generally works intended as textbooks, like those of van Musschenbroek and 's Gravesande. Besides Descartes, the only non-Newtonian work in the top 10 is Georg Hamberger's *Elementa Physices*, itself a textbook written by a university professor. The university allows authors a modicum of security: van Musschenbroek did not need to be explicitly novel (he could be a Newtonian in name), nor did he need to profile himself to attain his influence (a textbook has a more stable readership). The university was also in this period moving away from being an institution focuses on teaching only, also introducing research into the activities of professors. This new university context opens up the possibility of working within another's research program, continuing and developing its thoughts, in a way that the non-university context does not allow for (Heilbron 1979).

Newtonian masking is finally combined with a tacit agreement on what terms are open to innovation and which are not. In order to allow for changes in the conceptual framework while also ascertaining unity, Newtonians limit their innovation to particular terms within a broader selection of terms central to the discipline.[39] These terms are then changing in meaning, imprinting a necessary flexibility to the semantic picture of the Newtonians. Van Musschenbroek's insistence on the social stability of Newtonians is, even if rhetorical, itself normative: do not be like those Cartesians in their state of 'perpetual revolution,' instead, continue improving on the work of previous practitioners. Whatever Newton's intentions towards his past were, when he stated "If I have seen further, it is by standing on the shoulders of giants," (Newton 1675) he appears also to have been suggesting a way to keep going forward. Newtonians should look further by standing on each other's shoulders instead of following the revolutionary nature of Cartesians.

I have suggested that we can see three profiles in early modern natural philosophy with regard to their approach to innovation. However, the corpus does not cover a long enough period of scholasticism. This means that, even if scholasticism shows itself as a sedimented school that does not semantically innovate, this does not translate into a claim about earlier stages of the school's development. Baroque scholastics are perhaps not showing semantic innovation. But this does not imply that earlier scholastics have not developed their semantic profile. So, without results about earlier scholastics to draw on, how does their approach to innovativity come out from what is said of them in the literature?

[39] The selection of terms was limited; the other schools might have been innovating on similar terms I have not considered. Still, Newtonians are particular in showing their interest in innovating on similar terms.

Some scholastic practices agree with the Newtonian masking I have described. For example, Scholastics make overt avowals of agreement with accepted authorities, even if not always completely genuine (Novotný 2013). And they have a broad agreement on the nature of their research program and their semantic profile, where a significant amount of the terminology is kept stable. Socially, they organize themselves in the context of the university, allowing long running chains of influence via textbooks, as is the case for Newtonians. The only difference is that in this corpus we are seeing the tail-end of a long-running approach to knowledge acquisition. Scholasticism was shaken by the revolutionary spirit of Descartes and the Cartesians, only to return to steadier waters with the calmer Newtonian approaches to natural philosophy. The Descartes-inspired mechanicists noted this renewal of 'authority' in natural philosophy and worried about a return to the pre-revolutionary time. As Lind reports Adolf Hamberger (1737 – 1788, son of Georg Hamberger) saying, mechanicists compared Newton to a new Aristotle; fearing a renewal of the scholastic program of referencing the past:

> Newton's scientific reputation was undisputed. Even the mechanicists recognized his achievements, even if they also paired this with critical inquiries and did without the enthusiasm of the Newtonians, *who often turn*, as A. A. Hamberger (1774) rightly remarks*, their master into an "idol of the natural sciences", a "new Aristotle."* (Lind 1992, p.127, emphasis and translation mine)[40]

Yet, this criticism would not be enough to retain their revolutionary approach to scientific thought indefinitely.

5.6: The Canon and Innovative Authors

Looking at the first ten ranked authors, one thing is immediately obvious: two of the authors (Descartes and Newton) are well-known canonical authors in the history of (natural) philosophy. A general defense of a scholar of why they discuss either of these figures might take the following form: Descartes and Newton are pivotal figures in the history of (natural) philosophy; they set a new program for philosophy and many thinkers after them drew on their work. For example, van Ruler tells us about Descartes' impact that it was both widespread and penetrating:

[40] Original: „Newtons wissenschaftliche Reputation war allseits unbestritten. Auch die Mechanisten erkennen seine Leistungen an, wenn auch mit kritischen Rückfragen und ohne den Enthusiasmus der Newtonianer, die wie A. A. Hamberger (1774) durchaus zu Recht bermerkt, aus ihrem Meister oft einen "Abgott in der Naturlehre", einen "neuen Aristoteles" machten."

> One can hardly overestimate the historical significance of these now forgotten tracts […T]he Geometry (*Géométrie*) […] laid the foundations of analytic geometry, a science without which later seventeenth-century developments in mathematical physics would not have been possible […] (van Ruler 2019)

And, similarly, Smith tells us of Newton that his thought is the singular most influential work on modern physics: "Viewed retrospectively, no work was more seminal in the development of modern physics and astronomy than Newton's *Principia*." (Smith 2008)

Clearly, a historical interest in these figures appears to be justified merely by these authors' impact on the development of thought, if these claims are true. And the above results agree with these statements, as, Descartes and Newton were novel and influential authors in the history of natural philosophy according to the innovativity scores generated.

Such a justification focuses, as Lisa Shapiro notes, on the causal factors of canon inclusion (2016). One of the pre-requisites in explaining the inclusion of authors in a canon is by explaining how the author stands in a larger discussion, where the author was successful to imprint their own particular ideas unto this broader context. and is central in the diffusion of their own particular ideas. Richard Schacht argues for such a view, where the canon of philosophy is a canon of thinkers who were important in the development of the discipline and how we think of philosophy today:

> The canon in philosophy may be thought of as certain thinkers who have had a good deal to do with the genealogy of our discipline, whose questions and ideas and ways of dealing with them are of interest in relation to ongoing inquiry, and who are among the most formidable explorers of various lines of inquiry that have caught on among us. (Schacht 1993, p.434)

Although it is clear that the causal impact of philosophers is not the only reason for including them, it might be taken to be at least one relevant factor for canon inclusion. From this I take that one of the possible 'virtues' an author or work might exhibit is novel influence, i.e., innovativity. I will return to the question whether innovativity really is a virtue for canon inclusion but let me for now assume that it is and check whether it is also de facto descriptive of the canon. To do so, I have asked three practicing historians of philosophy to annotate the authors in the corpus I am using for their level of innovativity, from 0 (completely unknown) to 3 (canonized). Underneath is a scatterplot of these results:

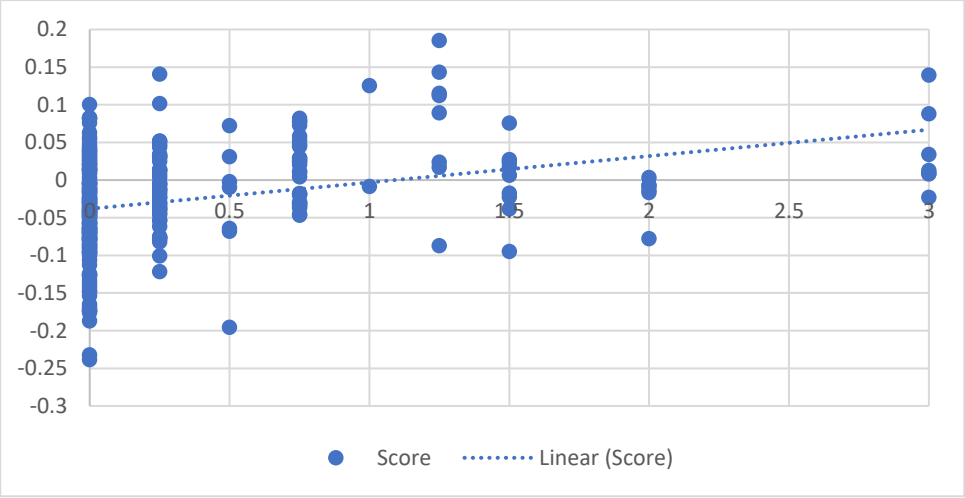

Figure 5.1: Scatterplot of innovation and canonicity scores of all works.

I find a weak (r = 0.34) positive correlation between canonized authors and authors being innovative in the corpus. This means that the current canon of early modern philosophers mirrors to some extent the innovativity of early modern natural thinkers. Such an observation could be leveraged in two ways. Firstly, it can be taken to justify the current canon. If the current canon and our current interest in history maps unto properties that justify our interest in them, and we find innovativity a worthwhile historical phenomenon that might justify our interest, then the current canon can be defended along those lines. And, secondly, it allows for an approach to the further extension of the canon. For example, a philosopher like Georg Hamberger might warrant further investigation given his work's high innovation score and low canonicity. In what ways has this author ascertained his disruptive position within this corpus of natural philosophy exactly?

Additionally, the finding agrees with Soni *et al's* (2020) findings: modern scientific articles showed that an increase in citations (a rough indicator of success in the same way as canonicity might be) is correlated with being semantically ahead of one's time. Whether cause or effect, it appears that scientific success and semantic innovation go hand in hand in modern science as well as in the early modern science.

These results do not necessarily justify our restricted interests in the history of philosophy; they only do so if we buy into the idea that there is either philosophical merit or historical merit in being innovative in the sense introduced in this chapter. I believe there to be no such philosophical merit; again, the relational nature of the measure ensures that nothing in favor of specific texts is ever said. However, I do

believe, as I explained above, that there are historical reasons to be more interested in the more innovative authors. If only given the inability to consider all the material in full detail, and thus forced to make selections, it seems reasonable to be interested in authors that are semantically ahead of their time–authors that are both influential and have some temporal priority.

Nevertheless, one important caveat is that innovativity as I defined it also considers a work's future influence (its continuity with its future). This means that authors whose voices are drowned out already during their own time will generally not score high on this measure. As Eileen O'Neill has shown (1997), there were mechanisms during early modern times that prevented women philosophers from being remembered (like female anonymous authorship being encouraged among other reasons). These add to other later causes for the lack of female philosophers in the canon. The discussed measure (and, in general, the causal approach) can only amend discrepancies between what during the period itself was new and influential and what is now no longer considered important enough to be significantly considered. However, if during the period itself the author is not emphasized, then this measure is not apt to remedy the discrepancy. Differently put, although it might be worthwhile to consider works that are significantly ignored and highly innovative, this cannot be in any way taken to be a comprehensive approach to extending canon inclusion.

5.7: Coherence

A number of the findings in this chapter seem to corroborate a 'standard' story of the development of early modern natural philosophy. Early modern natural philosophy can be helpfully defined in three schools struggling for dominance: scholastics, Cartesians and Newtonians. Internally, all these three schools are, to differing degrees, semantically stable. In attempting to extract the most innovative works from the corpus, both Descartes' and Newton's *Principles* stood out. The findings agree with the two works being foundational to their respective schools. Even though, based on stability, it seemed that the publication dates of these works were not particularly good moments to slice the corpus, in terms of innovativity these works are recovered as important moments in the development of natural philosophy.

As far as semantic innovativity is concerned, scholastics are unsuccessful, Cartesians somewhat successful and Newtonians the most successful. All these findings generally corroborate the standard accounts of what happened over the course of the sixteenth and seventeenth century in natural philosophy. Additionally, I compared frequencies of mentions of certain thinkers and checked whether there was a positive correlation with the innovativity scores. There was, providing some basis for the

conservative conclusion that the current canon maps unto historical relevance of the included authors.

On the other hand, however, some more unexpected results in this chapter also help us to understand better how these schools were (un)able to remain semantically innovative and stable. Scholasticism was already a long running tradition that had a strong emphasis on referring back toward earlier authorities. During these later centuries, it had already had a very well developed and precise conceptual vocabulary, not easily displaced. For Cartesians and their "New Philosophy," we find only Descartes himself as a major innovator. The revolutionary spirit of Cartesianism precluded them to build on each other's innovations and, instead, many great Cartesians work mostly in their own way on the Cartesian basis. Semantically, changes could not accumulate. Authors explicitly in disagreement with Descartes (like Anne Conway) appear semantically close; Descartes' influence extended widely, yet could not coalesce into a developing school.

Newtonians instead have a multitude of great innovators among their ranks. Besides Newton himself, they allowed for more people to rework the conceptual frame within which natural philosophy operated. How could this be done without sacrificing the unity of the Newtonian school? The greatest innovators are authors that position themselves as popularizers and that these innovators innovate semantically on a selection of terms. Newtonians mask their own innovation: explicit avowals of agreement with Newtonian are coupled with extensive yet carefully scoped semantic reworking. Careful scoping allows for significant semantic continuity, and explicit statements of similarity allow for social cohesion. Newtonians employed a successful semantic strategy that allowed them to retain their semantic status as a coherent school without being caught in an already sedimented semantic frame that could have potentially held them back.

6: Conclusion

Natural philosophers are not different from normal people. They work and think within the confines of the language that they have available, amending, changing or keeping it the same in order to further personal, social and epistemic goals. The strategies might both consist in changing terms in order to better account for the world or to better constitute their continuity with those who they perceive (or would like to have perceived) their peers.

Early modern natural philosophy showed sides of itself that were unexpected and sides that we had expected to find. For example, the innovativity of Descartes' *Principles* was to be expected. Similarly, we found Newtonians in the role of innovators; however, we unexpectedly find that some of the Newtonian popularizers were more innovative than Newton himself. In this way, Newtonians function as a school of thought: the unity of physics after Newton was not only provided by Newton himself, but also by tacit agreements on what topics, and even concepts, were still open for alteration and which were not. This provides a sufficiently flexible 'theory' that can remain socially unified by explicit avowals of agreement with others. Additionally, the schools of natural philosophy all generally came out as particularly stable groups of conceptual similarity.

As the method finds similarities irrespective of doctrinal agreement and, instead, tries to find similarities based on the broad conceptual and linguistic frames within which the works are written, doctrinal agreement would only come out as an engine of similarity if it agreed with conceptual distance. This was not the case throughout the dissertation. I have argued that the greatest conceptual sources for Anne Conway were Descartes and Hobbes, two authors she actively disagrees with in her *Principles*. Doctrinal disagreement does not block conceptual closeness. In fact, conceptual similarity as operationalized in this dissertation, generally does not map unto doctrinal agreement. It, however, does map unto school formation and picks disciplinary works (central in its formation and sedimentation) out as particularly innovative.

Meanwhile, I showed that word stability and salience mapped unto many of the general intuitions we might have had about early modern natural philosophy. A pretty clear sense was that words that come from a scholastic context and that get reworked by Cartesian and Newtonian authors later were conceptually unstable – with, of course, a clear hypothesis on the table about what the reason might be. However, these results sometimes contained unexpected outcomes; for example, a highly contested term like 'corpus' came out as particularly stable. It was only by adding salience differentiation that a more satisfactory image could be generated, in which it

turned out that ‘corpus’ plays a particularly special role in the collection of texts under scrutiny, which I have dubbed “Integral controversy term.” ‘Corpus’ is claimed to be a term that helps in the unification of a generally fractured school discourse, as it allows for explicit disagreement, but unifies due to tacit agreements about the ways the term should be used.

Methodologically, this dissertation has shown the importance of an extensive interpretation of algorithmic procedures. This is brought in the dissertation due to the “stacking” of interpretations. Chapter 4’s suggestion that semantic similarity can be interpreted as an indicator of influence allows for the definition of Chapter 5’s ‘innovativity’ measure. Innovativity being built up from a score that shows how much a work was influenced (continuity with the past) and how much a work influenced other works (continuity with the future). Similarly, it is the interpretation of average connection strength as stability in Chapter 2 and the pluralistic approach to meaning in Chapter 3 that allowed the salience differentiation of semantic algorithms, leading to the helpful categorization of terminology Chapter 3 ends with. The development of techniques, thus, depends partly on the development of interpretative frames that allow the further conceptual stacking of new applications.

A big historical pattern I found is that early modern natural philosophy shows structures that are still emulated in modern science, as there is a connection with being innovative and being well received (in EM) and well cited (in modern disciplines). This suggests that similar pressures are here at play, particularly the structures of agreement on the topics of conceptual innovation found in the Newtonian innovators. It would be interesting to see whether these inklings of more general claims could generalize into more domains of knowledge acquisition. Do we need conceptual agreement and agreement on where we are allowed to disagree conceptually in order to successfully develop more knowledge? Are there no corpora that will resist this pattern of school formation? Is doctrinal agreement ‘inconsequential’ to the development of the discipline as long as the terms and concepts are left in place? On the assumption that the answer to these questions is ‘yes’, we will have tools at hand to identify the most central terms in the development of disciplines and in finding routes of conceptual influence.

6.1: Going forward: Computational History of Philosophy as Big History? Upshots and Pitfalls

Recently, Ted Underwood has argued that one of the major advantages computational semantic analyses provides to literary history is that it allows for finding *longue durée* structures to the development of literary works in ways that are not available to the local vantage points of period-specialists who base themselves on close-reading (Underwood 2019). Rens Bod recently applied digital tools to help write a temporally encompassing history of the humanities, stating that the methods allowed him a breadth of analysis that would otherwise have been hard to achieve (Bod 2022). A historian of concepts or of philosophy, might find the prospect of tracing temporally extensive strands of thought attractive. Computational methods seem to provide us with a possibility to move past microhistories and minute commentaries as the only viable route for doing comprehensive humanistic history. Computational history might be most alluring when understood as a way of doing big history.

However, when we expand our scope of inquiry, we will by necessity invoke general theories to fill in the blanks on our now too large canvas of history. To understand society at large in times past, we also need our knowledge of the functioning of society now, as the fourteenth century historian Ibn Khaldūn (1332 – 1406) already noted:

> If [the historian] trusts historical information in its plain transmitted form and has no clear knowledge of the principles resulting from custom, the fundamental facts of politics, the nature of civilization, or the conditions governing human social organization, and if, furthermore, he does not evaluate remote or ancient material through comparison with near or contemporary material, he often cannot avoid stumbling and slipping and deviating from the path of truth. (Ibn Khaldūn 2015, p.11)

Similarly, to understand the history of concepts and philosophy, through linguistic expressions, the historian of concepts or the historian of philosophy needs to invoke their best theories of algorithmic modelling and the functioning of language. This historian will then also need to be explicit about their own current theories of language (which they in turn must get from linguists) and why their algorithms model semantics (which they must get from computer scientists first and then rigorously interpret and reinterpret). All the while, the historian must be aware that their attempt at weaving together large amounts of materials into a coherent theory of the development of a discipline are going to fail to consider all the available evidence (no matter that digital tools help us consider more evidence).

Surely, I have only succeeded partially in explicating my underlying theories that allowed for the broad application of methods in this dissertation. Similarly, I have only tentatively pointed towards broader tendencies in the development of scientific thought, by drawing parallels between early modern natural philosophy and current day science. However, keeping these ideal goals and important restrictions in mind, the history of concepts and the history of philosophy can look forward to new and exciting possibilities for the investigation of the development of thought in its most extensive and encompassing movements.

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8: Appendix 1: All (Short) Titles of Digitized Works by Language

LATIN:

1599 CASE Lapis Philosophicus
1600 CASE Ancilla Philosophiae Seu Epitome
1600 GILBERT De Magnete Magnetisque Corporibus
1600 MARTINI Disputatio Physica De Principii Servum Naturalium
1601 BALDUIN Accessitinfine discursus de sano physicae usuin rebus
1603 HIPPIUS Problemata physicaet logica peripatetica
1603 TAURELLUS Nicolai Taurelli In Inclyta Norimbergensium Academia
1604 GŌCKEL Physicę complete speculum
1605 HOCK Theses Physicae
1605 SCHRECKENFUCHS Disputationes Physicae
1606 KECKERMANN Disputationes Philosophicae Physicae Praesertim Quae
1606 STRAUCH Disputatio De Scientiae Naturalis Constitut
1606 STRAUCH Physica Specialis Duodecim Disputationum Aphorismis
1606 WESTPHAL Disputationum Physicarum Prima
1607 KECKERMANN Contemplatio gemina prior ex generali physica de locoal
1607 SNELLIUS Partitiones Physicae
1607 TIMPLER Physicæ seu Philosophiæ Naturalis systema methodicum intres partes digestum Pars prima
1608 STRAUCH AuspiciisSacrosanctae Et Individuae Trinitatis Ennea
1609 HIPPIUS Excellentissimi Philosophi M Fabiani Hippii Problemat
1609 HOFFMANN Theses Physicae
1610 VELSTENIUS Collegium Acroamaticum Seu Disputationes Physiologicae
1611 HUBMEYER Decas
1612 SUDANUS Disputatio Philosophica
1612 TITIUS Theses Physicae De Natura
1613 GOCLENIUS Physicae generalis libri II
1613 GUTBERLETH Physicae Hoc Est Naturalis Philosophiae
1613 SUDANUS Theses Selectae
1614 FELIX Disp phys de mundi constitutione
1614 GAUDIN Divina naturalis et rationalis philosophia
1615 HIERAT Aristotelis Aliorum que Philosophorum Ac Medicorum Pro
1615 JACCHAEUS Institutiones Physicae
1615 MÜLLER Disputatio Physica De Motu
1615 WASSERFHURER Physica Seu Synopsis Physicae Generalis
1616 Faber Philosophia Naturalis Duns Scoti
1616 MAGIRUS Physiologiae peripateticae libri sex cum commentariis
1616 SLEKER Philosophica Quadriga Cum Auriga
1617 ABRA De RACONIS Totius Philosophiae Brevis Tractatio
1617 KECKERMANN Systema physicum
1617 MALMÖ Casp Bartholini Deterra aereet igni institution physica
1618 CRASSOT Physica
1618 HORNEIUS Compendium Naturalis Philosophiae
1618 SENNERT Danielis Sennerti Vratis laviensis Epitome naturalis
1618 SENNERT Danielis Sennerti Epitome naturalis scientiae
1619 BARANZANO Novae Opiniones Physicae
1619 CAPITTEL Motus Physicus Ad Locum
1619 CRASSOT Totius Philosophiae Peripateticae Corpus
1619 LaROCHE Physicarum Dissertationum
1620 BACON Instauratio Magna
1620 BACON Novum Organum Scientiarum
1620 COMBACH Physica
1620 ERNDLIN De corporum naturalium causis
1620 ERNDLIN Disp phys de corporum naturalium principiis
1620 GORLAEUS Exercitationes Philosophicae
1621 CARPENTER Philosophia Libera
1621 RHOER Exercitatio Philosophica
1622 BACON Abcedarium Naturae
1622 BACON Historia Naturalis
1622 BACON Historia Ventorum
1622 BURGERSDIJK Idea Philosophiae Naturalism
1622 HORNEIUS Disputatio Physica
1623 BACON De Augmentis Scientiarum
1623 BACON Historia Densi Et Rari
1623 BACON Historia Gravis Et Levis
1623 BACON Historia Vitae Et Mortis
1623 ESPAGNET Enchiridion Physicae Restitutae
1624 GASSENDI Exercitationum Paradoxicarum Adversus Aristoteleos Libri Septem
1625 MORISANUS Apotelesma
1625 PICCART Clavis Peripateticae
1625 WENDELIN Quae Physiologia Generalis De principiis affectionibus
1626 RASPE Disputatio Prima De Natura Et Constitutione Physicae
1627 BACON Sylva Sylvarum
1629 RAMSAY Decermina Quaedam Philosophica
1630 BILDSTEIN Physica Paradoxa
1630 CHALMERS Selectae Disputationes Philosophicae
1630 CRASSOT Institutiones In Universam Philosophiam Aristotelis
1631 BURGERSDIJK Idea Philosophiae
1631 FROMMANN De Quaestionibus Et Dubiis
1632 BERIGARD Dubitationes In Dialogum Galilaei Galilaei
1632 CELLARIUS Institutiones Physicae
1632 WEISS Acroamata physica
1632 ZAPF Dubia physica operâtàm publicâ quàm privatâm Nico
1633 LEUSCHNER Tetras Disciplinarum Philosophicarum
1634 SPERLING Oratio de physica lucente
1634 SPERLING Tractatus physico medicus de origine formarum
1636 SENNERT Hypomnemata physica
1637 FABER Quaternarius Caussarum Physicarum Quem In Catholica

1639 SCHRAGMÜLLER Enantiophanon Physikon
1640 BURGHABER Theses Philosophicae Ex Octo Libris Physicorvm
1641 BOOTIUS Philosophia Naturalis Reformata
1641 RECHLINGER Philosophia Naturalis
1642 WHITE De Mundo Dialogi Tres
1643 DEUSING De Mundi Opificio Discursus Physicus
1643 DEUSING De Vero Systemate Mundi
1644 BEECKMAN Mathematico Physicarum Meditationum
1644 DESCARTES Principia Philosophiae
1644 DEUSING Naturae Theatrum Universale
1644 MERSENNE Cogitate Physico Mathematica
1644 SENGUERD Introductio Ad Physicam
1644 STADLMAYER Philosophia Tripartita Logica Physica Metaphysica
1645 KYPER Institutiones Physicae
1645 Le CAZRE Physica Demonstratio
1646 FABRI Tractatus Physicus De Motu Locali
1646 NOEL Aphorismi Physici
1646 REGIUS Fundamenta Physices
1647 Du CHESNE Selectae Dissertationes Physico Mathematicae
1647 MAGNEN Placita Logicae
1648 LINDEN Disputatio De Natura
1648 LINDEN Disputatio Physiologica De Partibus Generationis
1648 NOEL Physica Vetus Et Nova
1648 RUEDORFFER Ens mobile generabile et corruptibile
1649 BASSON Philosophiae Naturalis Adversus Aristotelem Libri XI
1649 BERTLINGI Controversiarum Philosophicarum Decas
1649 COMPTON Philosophia Universa
1649 NEUHAUSER Disputatio Physica Acroamatica
1649 SPERLING Synopsis Physica Johannis Sperlings
1649 ZEISOLD Decas disputationum physicarum deformarum substantia
1650 AMAMA Disputatio Physiologica De Spiritbus Et Facultatibus
1650 ISENDOORN Medulla Physicae
1650 TREW Oratio Inauguralis De Mutua Physicae
1651 AMAMA Dissertationum Marinarum Decas
1651 De MEY Commentaria Physica
1651 GILBERT De Mundo Nostro Sublunari
1651 GORLAEUS Ideae Physicae
1651 HOLWARDA Philosophia Naturalis
1652 BRUYN Disputatio Physica Miscellanea
1652 CRESPIN Commentarii Tres In Universam Aristotelis Philosophiam
1652 PROBST Principia et causae corporis naturalis
1652 SENGUERD Collegium Physicum
1652 STIER Praecepta Doctrinae Logicae
1653 BRUYN Disputatio Physica Continens
1653 BURGHOFF Compendium tripartitae philosophiae
1653 De BRUYN Disputatio Physica
1653 KLENCK Disputationes Physicae Quindecim
1653 LIPSTORP Specimina Philosophiae Cartesianae
1653 MAIGNAN Cursus Philosophicus
1654 CHARLETON Physiologia Epicuro Gassendo Charltoniana
1654 De RAEY Clavis Philosphiae Naturalis
1654 GRAFFT Cursus Philosophici Thetikos
1654 HEEREBOORD Philosophia Naturalis Moralis Rationalis
1654 TREW Disputatio Physica Continens Quaestiones Aliquot De Meteoris
1655 FOURNENC Universae Philosophiae Synopsis
1656 HOBBES Elementa Philosophiae
1656 LALEMANDET Cursus Philosophicus
1656 TREW Physica Aristotelica
1657 BRUYN Disputatio Physica Qua Rationes
1657 WHITE Euclides Physicus
1658 GASSENDI Syntagma Philosophiae Epicuri
1658 SENGUERD Physicae Exercitationes
1658 SPERLING Positionum Physicarum Pentadecas
1658 TREW Decas Quaestionum Physicarum Hodie Controversarum
1659 TREW Decas Quaestionum Ex Scientia Naturali Deprompta
1660 CLERKE De Plenitudine Mundi
1660 Le REES Cursus Philosophicus
1660 SCHOOCK Physica generalis
1661 DEUSING Disquisitio Physico Mathematica
1661 GAUTRUCHE Institutio Totius Philosophiae
1661 HOBBES Dialogus Physicus Sive De Natura Aeris
1661 LINNUS Tractatus De Corporum Inseparabilitate
1661 TREW Abdiae Trew defensio physicae Aristotelica
1661 VOET Physiologia
1662 CHABRON Philosophia Per Breviter Argumenta Explicata
1662 CLERKE Tractatus De Restitutione Corporum
1662 DERODON Disputatio De Atomis
1662 DESCARTES De Homine
1662 DEUSING Considerationes Circa Experimenta
1662 HOBBES Problematica Physica
1662 JUNGE Doxoscopiae physicae minores sive isagoge physica
1662 SCHOTT Physica curiosa sive mirabilia naturae et artis libris X
1662 SCHUYL Renatus Descartes De Homine Figuris
1662 SCHWENCK Decuria Positionum Physicarum Exhibens Hyetologian
1663 BRUYN Epistola Ad Isaacum Vossium
1663 SCHOOCK Physica Celestis
1663 SPINOZA Renati Descartes Principiorum Philosophiae
1664 CLAUBERG Physica
1664 GREYDANUS Institutiones Physicae
1664 KILIAN Fr Joan Duns Scotus ordinis Minorum doctor subtilis peru
1664 MAILHAT Summa Philosophiae
1664 VISLER Philosophia sacro profana logicam physicam et metaphysicam
1665 BRUYN Positiones Philosophicae Miscellaneae
1665 VISLER Conclusiones Physicae De Causis In Specie Earumque Caus
1666 SENNERT Danielis Sennerti Operum in quinqu et omosdiuisorum
1666 VINCENT Cursus Philosophicus
1668 BRUYN Disputatio Physica De Corporum Levitate Et Gravitate

1668 VOIGT Gothofredi Voigtii Curiositates Physicae
1669 BARROW Lectiones XVIII Cantabrigiae
1669 CHANEVELLE Physica Particularis
1669 COLUMBUS Novus Cursus Philosophicus Scotistarum
1669 GRAMM Quaestiones Physicae Metamorphosin Qua Uxor Lothiinst
1669 LAMY De Principiis Rerum Libri Tres
1669 MELLES Novum Totius Philosophiae Syntagma
1669 SINCLAIR Ars Nova Et Magna Gravitatis Et Levitatis
1669 WALLIS Mechanica
1669 WECH Dependentiaentis naturalis a suis causis physicis
1670 DUHAMEL De Corporum Affectionibus
1670 GOUDIN Philosophia Iuxta Inconcussa
1670 HUNDESHAGEN Johannis Christophori Hundeshagen Exercitationes
1670 KIPPING Institutiones philosophiae natural
1670 PINY Cursus philosophicus thomisticus
1671 FABRI Physica
1671 GUILLEMINOT Selectae Ex Universaliore Philosophia Quaestiones
1671 LEIBNIZ Hypothesis physica nova qua phaenomenorum natura
1671 RHODES Philosophia Peripatetica
1671 SANDERSON Physicae Scientiae Compendium
1671 VRIES Disputatio Philosophica Mundo
1672 GLISSON Tractatus De Natura Substantiae Energetica
1672 LeGRAND Institutio Philosophiae
1672 SANDERSON Logicae Et Physicae Artis Compendium
1672 STURM De Authoritate Interpretum Naturae Ac Speciatim
1672 WEIGEL Universi corporis pan sophici caput summum
1673 AMBLING Theses Physicae De Causis Corporis Naturalis
1673 DIRRHAIMER Theoremata Selecta Ex Universa Philosophia Peripateti
1673 DUHAMEL De Corpore Animato
1673 GRAU Specimina Philosophiae Veteris
1673 Le GRAND Historia Naturae
1673 SCHOOCK Dissertatio Physica De Nive
1673 STRAUSS Physicarum Decas De Elementis
1673 WEIGEL Physicae Pansophicae Specimen primum
1674 CALLY Institutio Philosophiae
1674 CASIMIR Atomi Peripateticae
1674 GSCHWENDTNER Naturalis philosophiae theoremata ad mentem doctoriss
1675 BARBAY Commentarius In Aristotelis Physicam
1675 HEINLEIN Disputationes phys de principiis rerum natural
1675 KHAMM Quaestiones disputatae ex Physicae
1675 LUDESCHER Quaestiones Physicae
1675 MERON Philosophia Scoto Peripatetica
1676 BARBAY In Universam Aristotelis Philosophiam Introductio
1676 HERMANN Sol Triplexine Eodem
1676 PITCAIRNE Compendiaria Et Perfacilis Physiologiae Idea
1677 VINCENT Discussio Peripatetica
1678 Du HAMEL Philosophia Vetus Et Nova
1678 VILLEMANDY Philosophiae Aristoteleae Epicureae Et Cartesianae Parallelismus
1679 GOUILLEMINOT Dissertationes De Principiis Intrinsecis
1679 RASSLER Quaestiones Philosophicae Tergeminae Tribus
1681 De VOLDER Disputationes Philosophicae
1681 DUHAMEL Opera Philosophica
1681 GALEN Disputationum Physicarum Quinta
1681 HOPFFER Experimenta physica instituta et cum thesibus
1681 SEMERY Triennium Philosophicum
1681 SENGUERD Philosophia Naturalis
1681 VOLDER Disputationes Philosophicae
1683 BARROW Lectiones Habitae
1683 BERNOULLI Dissertatio De Gravitate Aetheris
1684 SANNIG Schola philosophica scotistarum seu Cursus philosophicus
1684 STRAUSS Isagoge physica inqua praeter praec
1685 HARTNACK Curiosa Naturae
1685 SCHWEITZER Compendium physicae Aristotelico Cartesianae
1686 DALRYMPLE Physiologia Nova Experimentalis
1686 LAMMERS Disputatio Philosophica
1686 STURM Philosophia Eclectica
1687 INNOZENZIII Iter Ad Astra
1687 NEWTON Philosophiae Naturalis Principia Matematica
1688 GEULINCX Compendium Physicae
1688 GEULINCX Metaphysica Et Liber Singularis De Motu
1688 GEULINCX Physica Vera
1688 LANGENHERT Compendium Physicae
1690 BOERHAAVE Disputatio Philosophica
1690 BOYVIN Philosophia Scoti
1690 BROCKTORFF Disputatio De Scientiae Naturalis
1690 GEULINCX Annotata Praecurrentia
1690 WILLIS Synopsis Physicae Tam Aristotelicae
1691 GEULINCX Annotata Majora
1691 HÖRWART Decasscoto physica ex octo libris aus cultatorii deriva
1692 CAUVIN Cursus Philometaphysicus
1692 DuPASQUIER Summa Philosophiae Scholasticae Et Scotistae
1692 OHM Summa Philosophica In Tres Partes Divisa
1693 FRASER Determinationes Philosophicae
1693 PLEY Cursus Philosophicus Aristotelico Thomisticus
1693 VOGL Philosophus Rationalis Naturalis Et Transnaturalis
1694 SPERLETTE Physica Nova
1695 CALLY Universae Philosophiae Institutio
1695 CONNOR Dissertationes Medico Physicae
1696 Le CLERC Physica Sive De Rebus Corporeis

1697 BRISACENSIS Cursus Philosophicus
1697 DUHAN Philosophus In Utramque Partem
1697 KOCH Philosophia naturalis sive physica centum assertionibus comprehensa
1697 RENTZ Philosophia Secundùm Mentem Angelici Doctoris Divi
1697 STURM Physica Electiva Sive hypothetica
1698 HUYGENS Kosmotheoros
1698 STUART Theses phys de rerum naturalium principiis
1698 VOLDER Oratio De Rationis Viribus
1699 LINGEN Medulla Tripartita Philosophiae Veteris
1700 BAYLE Institutiones Physicae
1700 VEIEL Diss de elemento aquae et variis eius affectionibus
1701 BOERHAAVE Oratio De Commendando
1701 KEILL Introductio Ad Veram Physicam
1702 GREGORY Astronomiae Physicae Et Geometricae Elementa
1703 BECHER Physica subterranea profundam subterraneorum genesin
1703 oKELLY de AGHRIM Examen Philosophicum
1703 SAGUENS Philosophia Maignani Scholastica
1704 CLERC Opera Philosophica
1704 SANTVOORT Dissertatio Philosophica
1704 STURM Physica Modernae Sanioris Compendium Erotematicum
1705 LINGEN Cursus Philosophicus
1705 MÜLLER Oratio de utilissima physicae tractatione
1706 BABENSTUBER Philosophia Thomistica Salisburgensis
1707 PICHLER Obiectum Philosophiae Tripartitae
1708 ANDALA Exercitationes Academicæ In Philosophiam Primam Et Naturalem
1708 GAKENHOLZ Programma De Immunditie Ex Contrectatione Mortuorum
1708 WENZEL Analecta Philosophica Seu Nonnullae Quaestiones Physici
1709 BOERHAAVE Oratio Qua Repurgatae Medicinae
1710 GLOSEMEYER Theses Philosophiae Naturalis Curiosae
1710 HOLZEISEN Quaesita physicaserio curiosa de variis rerum naturali
1711 ANDALA Syntagma Theologico Physico Metaphysicum
1711 POURCHOT Institutiones Philosophicae
1712 ANDALA Dissertationum Philosophicarum Pentas
1712 SANDEN Sylloge Experimentorum
1713 JUENGKEN Compendium Physicae Eclecticae
1714 AEPINUS Introductio In Philosophiam
1715 MURALT Medulla Physica Erotematica
1715 SAGUENS Atomismus Demonstratus
1715 SCHMIER Physica Controversa
1716 HERMANN Phoronomia sive de viribus et motibus corporum solidoru
1716 SCHMIER Philosophia Quadripartita
1717 BOERHAAVE Sermo Academicus
1717 TEICHMEYER Elementa philosophiae naturalis experimentalis
1717 WUCHERER Programma DeCausa Motus Immediata
1718 BUDDEUS Programma de certitudine studii physici mathematica
1718 HANSCH Epistolae Ad Joannem Kepplerum Mathematicum Caesareum
1718 KASCHUBE Elementa physicae mechanic perceptivae
1719 ANDALA Cartesius Verus Spinozismi Eversor
1719 EPIE Dissertatio Prima
1720 ANDALA Disputatio Philosophica
1720 AYRMANN Specimen physicae rationalis de corporum coelestiumna
1720 GRAVESANDE Physices Elementa Mathematica
1720 WEBER Castrum Philosophico Peripateticum Oppugnatum
1721 SERRURIER Disputatio Physica Et Astronomica
1722 LEEUWENHOF Opera Omnia
1722 SERRURIER Physicae Experimentis Innixae Tractatio
1723 BUHON Philosophia Ad Morem Gymnasiorum
1723 GRAVESAND Philosophiæ Newtonianaes Institutiones
1723 MUSSCHENBROEK Oratio De Certa Methodo
1723 ODÉ Oratio De Laudabili Proscorum Hominum Methodo
1724 De CROUSAZ Oratio Inauguralis
1725 De CROUSAZ De Physicae Origine Progressibus
1725 SEDLMAYR Cursus philosophiae biennalis annus II
1726 MUSSCHENBROEK Elementa Physicae
1726 MUSSCHENBROEK Epitome Elementorum Physico Mathematicorum
1727 ODÉ Principia Philosophiae Naturalis
1728 BILFINGER De causa gravitates physica generali disquisitio
1728 FAYUS Trias Lectionum Physicarum
1728 VERDRIES Physica sive in naturae scientiam introductio
1729 GERLACIUS Dissertatio Physica De Natura
1730 JUNCKER Conspectus chemiae theoretico practicae informatabul
1731 KOENIG Oratio Inauguralis
1731 STAHL Experimenta observations animadversiones
1731 WOLFF Cosmologia generalis
1732 ENGELHARD Institutionum Philosophiae Theoreticae
1732 JURIN Dissertationes Physico Mathematicae
1733 RENTZ Philosophus Sympathetico Antipatheticus Sive Problem
1734 GRAVESANDE Orationes Tres
1734 HAGEN Meditationes philosophicae de methodo mathematica
1734 SPIES Positiones philosophicae De philosophia in genere
1735 JOHNSON Questiones Philosophicae
1735 KRISPER Philosophia scholae Scotisticae
1735 LOM Oratio De Vinculo
1737 GRAVESANDE Introductio Ad Philosophiam
1737 KRÜGER Meditationes physicaea De attractione et vicentripeta
1738 BAUMEISTER Institutiones metaphysicae
1738 BERNOULLI Hydrodynamica sive de viribus et motibus fluidorum

1739 BOSE Otia Wittembergensia critic physica
1739 FRASSEN Philosophia Academica
1739 MAYR Philosophia peripatetica antiquorum principiis
1739 PANGER Philosophia aristotelica universa
1740 JALABERT Oratio Inauguralis De Philosophiae Experimentalis Utilitate
1741 HAMBERGER Elementa physices
1741 SEGNER Ad lectiones philosophiae naturalis experimentalis publicas invitatio
1742 BERNOULLI Opera Omnia
1742 BILFINGER Elementa physices
1744 SCHNELL Cursus philosophiae Aristotelico Thomisticae abbreviatus
1745 SCHEIDT Ethica philosophica
1746 BILFINGER Dilucidationes philosophicae de Deo anima humana mundo
1746 DAGOUMER Philosophia Ad Usum Scholae
1748 KOENDIG Cursus binaries idest naturalis supernaturalis
1748 KÄSTNER Physicae iurisprudentiam illustrantis specimina
1748 MUSSCHENBROEK Institutiones Physicae
1749 BRUGMANS Disertatio Philosophica Inauguralis
1750 CANZ Meditationes Philos
1750 KRAFFT Praelectiones Academicae Publicae In Physicam Theoreticam
1750 KRETZ Biennium peripateticum
1751 KHELLBURG Physicae recentiorum observationibus accommodataus
1752 KRAFFT Theses inaug math phys de numero parirectis parallelise
1752 KÄSTNER Ademinentissimum Principem Angelum Mariam Quirinumde
1752 KÖNIGSEGG Theses Menstruae Ex Physica De Æquilibrio Pressione
1753 GUFL Philosophia Scholastica Universa
1753 HOLLMANN Philosophiae naturalis primae lineae
1753 KRÜGER Philosophia naturalis experimentalis confirmata
1753 SCHERFFER Institutionum Physicae
1753 WOLFF Physica experimentalis
1754 MÜLLER Petra Simoniana Seu Ratocinia Physica
1754 OBERHAUSER Principia Corporis Naturalis
1755 REDLHAMER Philosophiae Naturalis
1755 REGNAULT Physicae Recentioris Origo
1756 CARTIER Philosophia eclectica
1756 KROPH Theses Selectae Ex Universa Philosophia Peripatetica
1757 De La CAILLE Lectiones Elementares Astronomicae
1760 SIGORGNE Astronomiae Physicae Juxta Newtoni Principia
1762 HANOV Philosophia Naturalis Sive Physica Dogmatica
1762 MUSSCHENBROEK Compendium Physicae Experimentalis
1763 AC Clarissi morum virorum Dissertationes physicae
1764 KREUSSLER Epitome physicae generali seclecticae exercitationibus
1765 BRUGMANS Tentamina Philosophica De Materia Magnetica
1765 EULER Theoria motus corporum solidorum seu rigidorum
1765 KOENIG Veritas quadrata mathematica physica philologica
1765 OSTERRIEDER Physica experimentalis et rationalis
1766 MAYR Philosophia Peripatetica antiquorum principiis
1767 BAUMEISTER Philosophia definitiva
1767 BRUGMANS Oratio Inauguralis De Proferendis Physices
1768 BIWALD Physica particularis quam Auditorum philosophiae
1768 BRUCHAUSEN Theses Ex Universa Logica Et Metaphysica
1769 ZALLINGER Lex Gravitatis Universalis Ac Mutuae Cum Theoria
1770 BURKHÄUSER Theoria corporis naturalis principiis Boscovichii conformata
1770 STATTLER Philosophia method scientiis propria explanata
1771 KAESTNER Dissertationes mathematicae et physicae quas societat
1771 SEGUY Philosophia Ad Usum Scholarum Accommodata
1772 BODTMANN Positiones philosophicae ex physica et mathesi
1772 ZALLINGER Diss de exposition physica demonstrationum
1773 GABLER Theoria Vaporum
1774 REICHENBERGER Cursus Biennalis Philosophiae Et Matheseos Universae
1774 ZALLINGER Interpretatio naturæ seu Philosophia Newtoniana
1775 BRUCHAUSEN Institutiones Physicae
1775 THOMAS Positiones Physicae
1776 MATHES Desystemate mundi
1777 ADAM Philosophia Ad Usum Scholarum Accommodata
1777 FORFAIT Solutio Problematis
1779 BECK Institutiones physicae praelectionibus
1779 MAYR Positiones ex Philosophia theoretica physica
1779 ZENGER Positiones Ex Physica Geometria Propugnabunt
1781 GABLER Theoria magnetis
1782 Para Du PHANJAS Theoria De Entium Sensiblium Sive Physica
1783 BECKER Positiones mathematico physicae
1783 SOLINGEN Theses Philosophico Physicae
1785 SWINDEN Oratio De Hypothesibus Physicis
1786 NIEUWLAND Oratio De Ratione
1786 SWINDEN Positiones Physicae
1788 HEINRICH Positiones Mathematicae Ac Physicae
1793 EYCK Oratio De Vi Matheseos Submlimioris
1796 IMHOF Positiones Ex Physica Generali Et Speciali Ac Sublimior
1799 HEINRICH Positiones Physicae Et Mathematicae

ENGLISH

1605 BACON Of The Proficience And Advancement Of Learning
1644 DIGBY Two Treatises
1646 WHITE Institutiones Peripate
1651 COMENIUS Naturall Philosophy
1655 Cavendish The Philosophical and Physical Opinions
1659 CHARLETON Natural History Of Nutrition Life Voluntary Motion
1660 BOYLE New Experiments Physico Mechanical
1661 BOYLE The Sceptical Chemist

1661 Digby A Discourse Concerning the Vegetation of Plants
1661 GLANVILL Scepsis Scientifica
1663 BOYLE Considerations Touching The Useful
1664 CAVENDISH Philosophical Letters
1664 POWER Experimental Philosophy in Three Books
1665 BOYLE Experiments And Observations Touching
1665 HOOKE Micrographia
1666 BOYLE Origin Of Forms And Qualities
1666 CAVENDISH Observations
1668 CAVENDISH Ground
1668 GLANVILL Plus Ultra
1669 BOYLE Certain Physiological Essays
1670 AM A Discourse Of Local Motion
1671 GLANVILL Philosophia Pia or a discourse of the Religious Temper
1674 BOYLE Animadversions
1674 BOYLE Tracts Containing Suspicions
1676 BOYLE Experiments And Notes About The Mechanical Origin Or Production Of Particular Qualities
1676 BOYLE Experiments Notes About The Mechanical Origin or Production of Particular Qualities
1677 HALE Observations Touching the Principles of Natural Motions
1678 HOBBES Decameron physiologicum
1682 BOYLE New Observations And Experimentations Made Upon The Icy Lunar
1682 DIGBY A Choice Collection of Rare Secrets and Experiments
1683 LISTER Letters and Divers Other Mixt Discourses in Natural Philosophy
1683 SINCLAIR Natural Philosophy Improven by Several Experiments
1686 BOYLE Free Enquiry into the Vulgarly Received Notion of Nature
1687 ABERCROMBY Academia Scientiarum
1687 MIDGLEY New Treatise Of Natural Philosophy
1692 BULSTRODE An Essay Of Transmigration Or A Discourse Of Natural Philosophy
1694 Le GRAND An Entire Body Of Philosophy
1696 SINCLAIR The Hydrostaticks or the Weight, Force, and Pressure of Fluid Bodies
1704 HARRIS A New Dictionary Of Arts And Sciences
1704 NEWTON Optics
1705 DITTON General Laws Of Nature And Motion
1705 HALLEY Miscellanea Curiosa
1705 PURSHALL An Essay At The Mechanism Of The Macrocosm
1709 HAUKSBEE Physico Mechanical Experiment
1714 HAUKSBEE A Course Of Experiments
1715 CHEYNE Philosophical Principles
1719 DESAGULiERS Newtonian System
1720 PIRRIE A Short Treatise Of The General Laws Of Motion
1723 HODGSON Miscellanea Curiosa
1725 ROBINSON A New Theory Of Physick And Diseases
1725 SHAW Robert Boyle Philosophical Works
1726 HOOKE Philosophical Experiments And Observations
1727 GREENE The Principles Of The Philosophy Of Expansive Contractive Forces
1727 MOTTE A Treatise On The Mechanical Powers
1727 STIRLING A Course Of Mechanical And Experimental Philosophy
1728 PEMBERTON View Of Newtons Philosophy
1730 CLARKE A Demonstration Of Some Of The Principal Sections
1730 WORSTER Principles Of Natural Philosophy
1732 DORMER A Physico Mechanical Essay
1732 HUTCHINSON Power Essential And Mechanical
1733 COOK Clavis Natura
1733 HALES Statical Essays
1734 DESAGULiERS A Course Of Experimental Philosophy
1734 LAW An Enquiry Into The Ideas Of Space Time Immensity Eternity
1735 CLARE Motion Of Fluids Natural And Artificial
1735 MARTIN The Philosophical Grammar
1738 ROWNING Compendious System Of Natural Philosophy
1738 SMITH A Compleat System Of Opticks
1740 BAXTER Matho
1740 MARTINE An Examination Of The Newtonian Argument
1743 EMERSON The Doctrine Of Fluxions
1743 HORSLEY A Short And General Account
1745 ROBERTSON The Principles Of Natural Philosophy
1746 COOPER Philosophical Enquiry Into The Properties Of Electricity
1746 NEEDHAM Letter From Paris
1746 POWELL Heads Of Course Of Lectures
1746 SHEPHERD Heads Of A Course Of Lectures
1747 WATSON Sequel To The Experiments
1747 WILSON An Essay Towards An Explication Of The Phaenomena Of Electricity
1748 KNIGHT Attempt To Demonstrate
1748 MACLAURIN Newtons Philosophical Discovery
1748 RACKSTROW Miscellaneous Observations
1748 RUTHERFORTH System Of Natural Philosophy
1748 WILSON The Principles Of Philosophy
1750 WILSON A Treatise On Electricity
1752 FREKE Treatise On Nature And Property Of Fire
1752 HILL Essays In Natural History And Philosophy
1753 CANTON Electrical Experiments
1753 HORNE State Of The Case Between Hutchinson And Newton
1753 PIKE Philosophia Sacra
1754 EMERSON Principles Of Mechanics
1756 WILSON Observtions On Aeries Of Electrical Experiments
1757 SIMPSON Miscellaneous Tracts
1759 SYMMER Experiments And Observations Conerning Electricity
1760 SYMMER New Experiments Etc Of Electrical Cohesion
1761 DELAVAL An Account Of Several Experiments
1762 JONES Essay On First Principles
1764 JOHNSON Course Of Experiments

1764 WILSON Short Observations
1766 WALKER Analysis Of A Course Of Lectures
1767 HAMILTON Four Introductory Lectures
1767 HAMILTON Philosophical Essays
1767 LANE Description Of An Electrometer
1767 PRIESTLEY History And Present State Of Electricity
1769 DONNE An Epitome Of Natural And Experimental Philosophy
1770 EMERSON Short Comment On Newtons Principia
1770 FERGUSON An Introduction To Electricity
1771 BERDOE An Enquiry Into The Influence Of The Electric Fluid
1772 FERGUSON Introduction To Newtons Philosophy
1772 HENLY An Account Of A New Electrometer
1774 ARDEN Analysis Of Mr Ardens Course Of Lectures
1774 FENNING The Young Mans Book Of Knowledge
1774 HENLEY An Accoun Of Some New Experiments In Electricity
1774 HOOPER Rational Recreations
1774 LOVETT The Electrical Philosophers
1775 BANKS An Epitome Of A Course Of Lectures
1776 ATWOOD A Description Of The Experiment
1776 EATON Abridgment Of Astronomy And Natural Philosophy
1776 ELIOT Elements Of The Branches Of Natural Philosophy
1776 FERGUSON Lectures On Select Subjects
1776 GOLDSMITH A Survey Of Experimental Philosophy
1776 HIGGINS A Philosophical Essay Concerning Light
1777 HENLEY Experiments And Observations In Electricity
1777 WALKER Syllabus Of A Course Of Lectures
1778 SWIFT Account Of Some Experiments In Electricity
1779 STANHOPE Principles Of Electricity
1780 LYON Experiments And Observations
1780 MOYES Heads Of A Course Of Lectures
1780 WILSON A Short View Of Electricity
1781 LYON Farther Proofs That Glass Is Permeable By Electric Effluvia
1781 MILLER An Inquiry Into The Cause Of Motion
1782 ELIOT Elements Of The Branches Of Natural Philosophy
1782 GREEN Epitome Of A Course Of Lectures
1783 MILNER Experiments And Observations In Electricity
1784 ATKINSON A Copmendium Of A Course Of Lectures
1784 ATWOOD A Treatise On Rectilinear Motion
1784 oGALLAGHER Essay On The Investigation Of First Principles Of Nature
1784 ROBISON Course Of Experimental Philosophy
1785 ADAMS An Essay On Electricity Explaining Theory And Practice
1785 TRIMMER Nature Displayed
1785 VINCE On The Motion Of Bodies Affected By Friction
1786 ANDERSON Institutes Of Philosophy
1788 BURTON Heads Of A Course Of Lectures
1788 NOAUTHOR An Abstract Of Astronomy Geography Natural Philosophy Mythology History
1789 BENNET New Experiments On Electricity
1789 BROOK Miscellaneous Experiments And Remarks On Electricity
1789 PEART On The Elementary Principles Of Nature
1789 PENROSE Letters Philosophical And Astronomical
1790 SMELLIE Philosophy Of Natural History
1792 BELL The General And Particular Principles Of Animal Electricity
1793 FOWLER Experiments And Observations Relative To The Influence Lately Discovered By MrGalvani
1793 VINCE A Plan Of A Course Of Lectures
1794 ADAMS Lectures On Natural And Experimental Philosophy
1794 BENNET Experiments And Observations Made With The Doubler Of Electricity
1794 MORGAN Lectures On Electricity
1794 TELESCOPE Newtonian System Of Philosophy
1795 VINCE The Bakerian Lecture Observation On The Theory Of The Motion
1795 VINCE The Principles Of Hydrostatics
1797 PEARSON Experiments And Observations
1797 WHYTE Syllabus Of A Course Of Experimental Philosophy
1798 GREGORY Economy Of Nature
1798 LANGWORTHY A View Of The Perkinean Electricity
1798 VINCE Bakerian Lecture
1799 ADAMS An Essay On Electricity Explaining Principles
1799 BREHM Inquiries In Natural And Experimental Philosophy
1799 WILKINSON An Analysis Of A Course Of Lectures
1800 JOYCE Scientific Dialog
1802 WALKER A System Of Familiar Philosophy
1814 HIGGINS Experiments And Observations
1815 HUTTON A Mathematical And Mechanical Dictionary

FRENCH

1601 GRAVELLE Abrege De Philosophie
1606 CHAMPAIGNAC Sommaire
1634 MERSENNE Les Questions Theologiques
1634 SOREL La Science Universelle
1636 ROBERVAL Traité De Méchanique Des Poids
1637 DESCARTES Discourse De La Methode
1640 HESTEAU Oeuvre De La Physique Naturelle
1641 CLAVE Nouvelle Lumiere Philosophique
1643 ABILLON La Physique Des Bons Esprits
1644 MOULIN La Philosophie Mise En Francois
1647 PASCAL Experiences Nouvelles

1647 PETIT Observation Touchant Le Vuide
1648 NOEL Le Plein Du Vuide
1648 ROCHAS La Physique Reformee
1653 Du ROURE La Physique Expliquee
1654 Du ROURE La Philosophie Divisee
1664 DESCARTES Le Monde De Mr Descartes
1664 La FORGE Remarques Sur Le Traittes Des Hommes
1665 De LOCQUES Les Rudimens De La Philosophie Naturelle
1665 Du ROURE Abrege De La Vraye Philosophie
1666 CORDEMOY Le Discernement Du Corps Et Del Ame
1670 DECHALES Discours Du Mouvement Local
1670 PARDIES Discours Du Movement Local
1671 ROHAULT Traite De Physique
1672 BOURDELOT Conversations
1674 LEBOSSU Parallel Des Principes De La Physique
1674 PARDIES La Statique Ou La Science Des Forces Mouvantes
1675 BAYLE Discours Sur LExpérience Et LaRaison
1675 LAGRANGE Les Principes De La Philosophie
1679 SAINT-ROMAIN La Science Naturelle
1680 PERRAULT Essais De Physique
1681 MARIOTTE Essays De Physique
1682 RESTAURAND LAccord Des Sentiments DAristote Et DEpicure
1684 DARMANSON La Beste Transformee A Machine
1688 BAYLE Dissertations Sur Quelque Questions
1690 DANIEL Voyage Du Monde De Descartes
1690 FURETIERE Dictionnaire Universel
1690 REGIS Systeme De Philosophie
1693 DANIEL Nouvelles Difficultes
1696 HARTSOEKER Principes De Physique
1705 PARENT Recherches De Physique Et De Mathematique
1706 HARTSOEKERS Conjectures Physiques
1706 Le CLERC Nouveau Systeme Du Monde
1708 HARTSOEKER Suite Des Conjectures Physiques
1709 POLYNIERE Experiences De Physique
1710 HARTSOEKER Eclaircissemens Sur Les Conjectures Physiques
1719 BOUGEANT Observations Curieuses
1719 DENYSE La Nature Expliquee
1722 HARTSOEKER Recueil De Diverses Pieces De Physique
1724 CASTEL Traite De Physique
1727 ELDER Discours sur les loix de la communication du mouvement
1729 BOURGUET Lettres Philosophiques
1730 BERNOULLI Nouvelles pensées sur le systeme Descartes
1730 HARTSOEKER Cours de Physique
1733 REGNAULT Les Entretiens Physiques
1734 REGNAULT LOrigine Ancienne De La Physique Nouvelle
1738 NOLLET Programme Ou Idee Generale
1740 CHATELET Institutions De Physique
1741 TRABAUD Principes Sur Le Mouvement
1743 CASTEL Le Vrai Systeme De Physique Generale
1743 CHESEAUX Essais De Physique
1747 BRANCAS-VILLENEUVE Système Moderne De Cosmographie
1747 VALLE Lettre Sur La Nature De La Matiere Et Du Mouvement
1748 BOUREAUDESLANDES Recueil De Différens Traites DePhysique
1748 NOLLET Lecons De Physique Experimentale
1750 PEZENAS Memoires De Mathematiques Et De Physique
1751 LANTHENEE Nouveaux Essais De Physique
1751 LAUNAY Respons Aux Principales Objections
1752 FONTENELLE Théorie Des Tourbillons Cartésiens
1753 BEAUSOBRE Dissertations Philosophiques
1753 NOLLET Oratio Habita
1753 SAVERIEN Dictionnaire Universel De Mathematique Et De Physique
1754 CHAPUIS Memoires De Physique Pure
1757 DAMBESIEUX Reflexions Sur La Physique Moderne
1758 DUFIEU Manuel Physique
1758 LEMONNIER Premiers Traites Elementaires
1760 HAUTECOUR Amusement Physique
1761 KERANFLECH Hypothèse Des Petits Tourbillons
1762 CHESEAUX Discours Philosophique
1762 MORVEAU Digressions Academiques
1763 PAULIAN Traite Des Paix Entres Descartes Et Newton
1763 SAINTIGNON Traite Abrege De Physique
1766 COCHET La Physique Experimentale Et Raisonnee
1766 DELISLE Parallele Entre Descartes Et Newton
1766 PERRIERE Nouvelle Physique
1767 PAULIAN Dictionnaire De Physique Portatif
1767 SIGAUD-LAFOND Lecons De Physique Experimentale
1768 RANCY Essay De Physique
1769 PAULIAN Systeme General De Philosophie
1770 GUYOT Nouvelles Recreations Physiques Et Mathematiques
1770 MIRABAUD Systeme De La Nature
1770 SOCIETE de PHYSICIENS Noveau Dictionnaire Raisonne De Physique
1771 CASTILLON Observations sur le livre intitule Systêmedelanatur
1772 DESHAYES Physique Du Monde
1772 HOLLAND Réflexions philosophiques sur le Systemedelanature
1772 PARA Du PHANJAS Theorie Des Etres Sensibles
1773 ROSNAY La Physique Des Dames
1777 SAURY Cours De Physique Experimentale
1777 TAITBOUT Abrege Elementaire
1778 HENNERT Dissertationes Physiques Et Mathematiques
1780 SAURY Precis De Physique
1781 BRISSON Dictionnaire Raisonne
1781 PARA Du PHANJAS Elemens De Physique
1781 PAUCTON Theorie Des Loix De La Nature

1782 CARRA Nouveaux Principes De Physique
1782 LACEPEDE Physique Generale Et Particuliere
1782 WAINDELACOURT Nouvelle Physique
1783 ROCHON Recueil De Memoires
1784 MARIVETZ Examen De La Physique Du Monde
1785 INGENHOUSZ Nouvelles Experiences Et Observations
1786 PARA Du PHANJAS Theorie Des Nouvelles Decouvertes
1786 SCHURER Elements De Physique
1787 SIGAUD-LAFOND Elements De Physique
1788 HEUBACH Precis De Physique
1788 PAULIAN Le Veritable Systeme De La Nature
1788 PRÉVOST De lorigine des forces magnétique
1789 BRISSON Traite Elementaire Ou Principes De Physique
1790 PAULIAN La Physique A La Portee
1792 PRÉVOST Recherches physico mécaniques sur lachaleur
1793 MONGE Encyclopedie
1795 VILLETERQUE Les Veillees Philosophiques
1796 CAZALET Theorie De La Nature
1799 PHILIBERT Histoire Naturelle

9: Appendix 2: Chapter 3 Subcorpus Selection

1644 DIGBY Two Treatises in the one of which, The nature of Bodies; in the other, The nature of Mans Soule, is looked into.
1646 WHITE Institutiones Peripateticae
1651 COMENIUS Naturall philosophie reformed by divine light, or, A synopsis of physicks
1654 CHARLETON Physiologia Epicuro-Gassendo-Charltoniana: or a Fabrik of Science Natural, Upon the Hypothesis of Atoms, Founded by Epicurus, Reparied by Petrus Gassendus, Augmented by Walter Charleton
1661 BOYLE The Sceptical Chymist (2 ed: ... Whereunto is Added a Defence of the Authors Explication of the Experiments, Against the Obiections of Franciscus Linus and Thomas Hobbes
1663 BOYLE Considerations touching the Usefulness of Experimental Natural Philosophy
1666 BOYLE Origin of Forms and Qualities according to the Corpuscular Philosophy
1666 CAVENDISH Observations on Experimental Philosophy
1668 CAVENDISH Grounds of Natural Philosophy
1686 BOYLE A Free Enquiry into the Vulgarly Received Notion of Nature
1687 MIDGLEY A new treatise of natural philosophy, free'd from the intricacies of the schools adorned with many curious experiments both medicinal and chymical
1694 LE GRAND An Entire Body of Philosophy according to the principles of the famous Renate Des Cartes in three books.
1704 NEWTON Opticks
1709 DITTON The General Laws of Nature and Motion, with their application to mechanicks. Also the doctrine of centripetal forces and velocities of bodies describing any of the conick sections, being a part of the great Mr. Newton's principles
1722 WORSTER A compendious and methodical account of the principles of natural philosophy
1727 STIRLING A course of mechanical and experimental philosophy : consisting of Seven Parts.
1727 GREENE The Principles of the Philosophy of the Expansive and Contractive Forces; or, An Inquiry into the Principles of the Modern Philosophy, that is, into the Several Chief Rational Sciences, which are Extant
1728 PEMBERTON A View of Sir Isaac Newton's Philosophy
1743 HORSLEY A Short and General Account of the most Necessary and Fundamental Principles of Natural Philosophy
1745 DESAGULIERS A course of Experimental Philosophy
1744 ROWNING A Compendious System of Natural Philosophy
1745 ROBERTSON The principles of natural philosophy explain'd and illustrated by experiments; in a course of sixteen lectures
1748 KNIGHT An attempt to demonstrate that all the phaenomena in nature may be explained by two simple active principles, Attraction and Repulsion: Wherein the Attraction of Cohesion, Gravity and Magnetism are shewn to be One and the Same and the Phenomena of the Latter are more Particularly Explained
1748 RUTHERFORT A System of Natural Philosophy; being a Course of Lectures in Mechanics, Optics, Hydrostatics and Astronomy
1748 MACLAURIN An Account of Sir Isaac Newton's Philosophyical Discoveries
1754 EMERSON The Principles of Mechanics: explaining and demonstrating the general laws of motion, the laws of motion, the laws of gravity, motion of descending Bodies, projectiles, mechanics powers, pendulums, center of gravity etc. strength and stress of timber, hydrostatics, and construction of machines
1754 WILSON The principles of philosophy. The principles of natural philosophy: with some remarks upon the fundamental principles of the Newtonian philosophy
1763 JONES An essay on the first principles of natural philosophy
1772 FERGUSON An easy and pleasant introduction to Sir Isaac Newton's Philosophy : containing the first principles of mechanics, trigonometry, optics, and astronomy
1774 ARDEN Course of lectures on natural and experimental philosophy. Viz. Natural philosophy in general, chemistry, electricity, mechanics, geography, astronomy, hydrostatics, pneumatics, optics
1774 HAMILTON Four introductory lectures in natural philosophy. : I. Of the rules of philosophising, the essential properties of matter, and laws of motion. II. Of the several kinds of attraction, and particularly of cohesion. III. Of gravity, or the attraction of gravitation. IV. The laws of motion explained, and confirmed by experiments.
1774 LOVETT The Electrical philosophers, Containing a New System of Physics
1774 FENNING The young man's book of knowledge : being a proper supplement to The young man's companion.
1775 BANKS An epitome of a course of lectures on natural and experimental philosophy.
1776 ATWOOD A Description of the Experiments intended to Illustrate a Course of Lectures on the Principles of Natural philosophy
1777 CULLEN First lines of physics, for the use of students in the University of Edinburgh
1784 ROBINSON Outlines of a Course of Experimental Philosophy
1784 ATKINSON A Compendium of a Course of Lectures on Natural and Experimental Philosophy
1787 TELESCOPE The Newtonian system of philosophy.

1789 PEART On the elementary principles of nature ; and the simple laws by which they are governed. Being an attempt to demonstrate their existence, and to explain their mode of action

1794 ADAMS Lectures on natural and experimental philosophy, considered in it's present state of improvement.

1795 WALKER Analysis of a course of lectures in natural and experimental philosophy

1798 ANDERSON Institutes of Physics

1798 GREGORY The Economy of Nature Explained and Illustrated on the Principles of Modern Philosophy vol.2

1798 GREGORY The Economy of Nature Explained and Illustrated on the Principles of Modern Philosophy vol.3

1800 WOOD The principles of mechanics : designed for the use of students in the University.

1804 ROBISON Elements of Mechanical Philosophy: Being the Substance of a Course of Lectures on that Science

1807 YOUNG A course of lectures on Natural Philosophy and the Mechanical Arts

1812 PLAYFAIR Outlines of Natural Philosophy

1862 WYLDE The circle of the sciences; a cyclopaedia of experimental, chemical, mathematical, and mechanical philosophy, and natural history

10: Appendix 3: Nederlandse Samenvatting

Elk Boek Zijn Eigen Babel: Conceptuele Eenheid en Verdeeldheid in Vroegmoderne Natuufilosofie

In deze dissertatie onderzoek ik de conceptuele ontwikkeling die plaats heeft gehad in vroegmoderne natuurfilosofie en de verschillende manieren waarop bepaalde concepten gebruikt werden door natuurfilosofische scholen. I onderzoek zowel de aard als de mate van conceptuele eenheid die zich voordoet binnen en tussen deze scholen, voor specifieke woorden. Ik gebruik hiervoor computationale tekstanalyse (ook wel vector semantiek genoemd) en ontwikkel deze methodes door. Door te kijken naar sleutelwoorden in vroegmoderne natuurfilosofie en de betekenis van deze woorden computationeel te modelleren, kan ik een overzicht genereren van een corpus van 731 natuurfilosofische werken uit de 17e en 18e eeuw. De drie belangrijkste scholen, scholastici, cartesianen en newtonianen, hebben allen verschillende mates van interne conceptuele cohesie en maken gebruik van verschillende semantische strategieën voor het doorontwikkelen van sleutelwoorden in hun vocabulaire.

Deze dissertatie poogt om inzicht te krijgen in hoe woorden en concepten veranderden doorheen vroegmoderne natuurfilosofie en, door dit te doen, te zien hoe verschillende auteurs en scholen in staat waren om mekaar te beïnvloeden, conceptuele eenheid te bewaren en verschillende semantische ontwikkelingsstrategieën te ontwerpen. Nadat hoofdstuk 1 de brede historiografische en methodologische context van de dissertatie uiteenzet, focust de dissertatie zich op vier hoofdvragen. Elk van deze vragen wordt (hoofdzakelijk) beantwoordt in een van de vier resterende hoofdstukken. Ten eerste, zijn de drie grote natuurfilosofische scholen conceptueel en semantisch verenigd of juist verdeeld (hoofdstuk 2)? Ten tweede, welke woorden spelen een meer centrale rol in de ontwikkeling van naturafilosofie en hoe doen zij dit (hoofdstuk 3)? Ten derde, kan semantische gelijkenis gebruikt worden om beïnvloeding tussen auteurs te traceren (hoofdstuk 4)? Ten slotte, aangenomen dat het antwoord op de vorige vraag ‘ja’ is, welke werken uit de 17e en 18e eeuw waren conceptueel innovatief en hadden daarmee een verstorende werking (hoofdstuk 5)?