Locating narrative in scientific papers

Ben Toth PhD

Acknowledgements

An early version of this paper was presented at the 3rd International Conference on Science and Literature, Sorbonne Universite, Paris 2 - 4 July 2018. I would like to thank Professor Mary Morgan for the invitation to develop this paper.

The conclusion they [animal psychologists] draw from mutilated bodies applies not to animals in the free state but to man as he is today. It shows that because he does injury to animals, he and he alone in all creation voluntarily functions as mechanically, as blindly and automatically as the twitching limbs of the victim which the specialist knows how to turn to account. The professor at the dissecting table defines these spasms scientifically as reflexes, just as the soothsayers at the altar once proclaimed them to be signs vouchsafed by his gods. Reason, mercilessly advancing, belongs to man. The animal, from which he draws his bloody conclusion, knows only irrational terror and the urge to make an escape from which he is cut off. (Horkheimer & Adorno 1944:p245)

Contents

0 Introduction	4
1 Textual analysis in science studies	6
The literary dimension of science studies	6
A literary turn in philosophy	8
Fictionalism and model based science	9
What sort of literary dimension?	10
Questioning the value of textual analysis in science	11
Scientific writing isn't narrative - realism, language, models, fictionalism	11
Realism	12
Language	13
Models	14
Fictionalism	15
Science is more than its written form	17
The presence of maths is a critical difference between scientific and non-scientific texts	18
2 Roland Barthes and models of narrative	24
Roland Barthes	24
Structure, narrative, close reading, and S/Z	26
The five narrative codes	27
Assembling the codes	28
Summary - text, code, fragment	30
3 The potential for applying S/Z to scientific texts	31
Scientific papers	31
Applying S/Z to a scientific paper	31
Which text to choose?	31
Do Barthes' narrative codes apply?	32
Are 5 codes sufficient?	34
4 A text analysed	35
I. Repetition	35
II Density	37
III Poetry	37
IV Action	38
V Realism	38
VI Models	41

VII Multiple readings	42
VIII Animals and humans	45
IX Masculine/feminine	46
X The chain of reference	49
5 Implications	51
Method	51
The five codes	51
Narrative, rhetoric, modelling	51
Is this a coherent and enabling theory?	52
Concluding thoughts	53
Bibliography	54

0 Introduction

Clearly, in a minimal and documentary sense, scientific papers are narratives - they account for and record the course and results of a scientific investigation. And they fall within more exacting definitions of narrative such as those of (White 1972) and (Carroll 2001 p118), as well being what the ancient Greeks called *diegeisthai*, which means literally ‘ “to lead/guide through” and which came to mean ‘give an account of, expound, explain, and narrate’ (Halliwell 2013). The modern tendency to equate narrative with folk tales and storytelling is not one the ancient Greeks would have recognised. For them narrative could apply as much to a legal disposition as a poem. ‘Narrativo’ wrote Roland Barthes, ‘involves two types of elements: facts and descriptions’ (Barthes 1970d :80).

Scientific papers may be narrative, but they are not novellas, poems, or any other literary construction. The story a scientific paper tells, radically different in form and intent from literary stories, is compact, dry, and meticulous; their careful verbal tread reaches out to reality in a way that fiction does not.

The premise of this working paper is that a common framework for understanding narrative can be applied across all types of storytelling without erasing the vital difference between - to put it at its starkest - fiction and nonfiction. The intention is descriptive rather than polemical. But as Nancy Bauer wrote in her study of Simone de Beauvoir, an act of description is also ‘implicitly [to] make a claim, or a set of claims, about what that thing is, about what, in other words, is to count’ (Bauer 2001 p2) Bauer wants to persuade her reader that when De Beauvoir was describing the conditions in which women live she was also unearthing the cultural assumptions about women’s lives. Similarly here, to describe scientific texts as narrative is to claim that they are connected with culture in ways beyond their artfully narrow style and the intention of their authors.

It has long been recognised that modern science has intensely interesting stories to tell about the world (Honey 1945); about subatomic structure, black holes, gravitational waves, the creation of the human body from stardust, computational thought, ecological recovery, cellular structure, and much else. Scientists, rather than novelists or poets, are in fact our culture’s chief storytellers. They are its worldmakers (Goodman 1976) and artful modellers (Cartwright 2019). But the stories are told in a culture which sponsors the unceasing division of different types of knowledge. On the one hand rationality, precision, logic; on the other by myth, emotion, magic. Art is invention, creation. Science is discovery, revelation. This division is as self-perpetuating as it is limiting. An overestimation of the possibilities of scientific knowledge - which at its worst is

positivism - is matched by a distrust in what people imagine science to be, which at *its* worst gives rise to fantasies of post-civilisation.

Something of what is at stake, why the border guards are alert¹, can be seen in the so-called two cultures controversy in the late 1950s (Collini 2013) and the science wars of the 1990s (Labinger and Collins 2001). Forty years apart, they are outcrops of a deeper dispute about 'contrary interpretations of what they understood to be modern civilizations' (Ortolano 2011 p256). In different ways, in specific contexts, each episode contrasted, unhelpfully, the self-absorbed culture of the arts with the objective culture of the sciences.

It has not always been this way (Lehoux 2012). The motivation of this essay is that there is some value in art and science regarding themselves as allies rather than competitors, and that one point of intersection is narrative (Morgan and Wise 2017). Specifically, I would like to test, or at least examine, the hypothesis that fictional works and scientific papers are subject to the same rules of formation, and that a now forgotten branch of literary theory might offer some insights into the semantic form of model based science.

It is necessary to emphasise that calling science narrative is not intended to suggest that the objects of its interest are fictitious. The argument I would like to make is that the reality of science - the ontological status of its objects and the epistemological status of its truths - is more complicated than it appears; that understanding these complications is worth the effort; that the arts, like science, create, embody and convey knowledge of the world; that the value of science is not lessened if the barrier between different ways of knowing were a bit lower; and that the benefit for all is the addition of morality to science, of value to facts.

The paper is organised into five sections:

1. [A review of textual analysis in science studies](#)
2. [Roland Barthes and models of narrative](#)
3. [The potential for applying S/Z to scientific texts](#)
4. [A worked example](#)
5. [Implications.](#)

¹ 'The point is to attempt to understand why so much has hinged on their being kept distinct - how their distinctness could have become axiomatic to scientific theory and practice, and what the costs of operating with such an axiom are' (Herman 1998 p387)

1 Textual analysis in science studies

The literary dimension of science studies

Studies based on what Peter Dear called the literary dimensions of science (Dear 1991) emerged partly in response to the difficulty of characterising science in terms solely of logic, and partly as a reflection of the wider linguistic turn in the humanities and social sciences.² The number of studies which took serious account of the written language of science was extensive by 1991, and is even more so now.³ The references below are not exhaustive; they simply indicate, in a rough categorisation, the breadth of scholarship that might be included in the literary dimension of science:

linguistics Studies of the syntax of scientific writing. For example Myrna Gopnik's extensive study, identifying linguistic structures (controlled experiments, hypothesis verification) in texts, formalising them with a view to developing a computable model of natural language (Gopnik 1972 p57). Linguistics continues to be an area of research into the possibility of automatic extraction of data from published reports (Kiritchenko et al. 2010) (Beltagy et al 2019), and the development of normative rules for writing scientific papers so that they can be machine-readable (Sim 2014).

rhetoric A very extensive range of studies of style and rhetoric in scientific writing. Overviews and bibliographies in (Gross 1996) (Locke 1992). Wilda Anderson conducted 'a literary analysis of a group of related texts, mostly about chemical subjects from the last half of the eighteenth century' (Andersen 1984 p2). James Wynn analysed the rhetoric of mathematics in science (Wynn 2012). Ludwig Fleck's study on the genesis of scientific knowledge included what he called thought styles, without translating this into formal rhetorical analysis (Fleck 1935). Many other texts, for example (McCloskey 2004) (Fahnestock 1999) (Cecarelli 2001) (Woolgar 1983). Critical review of the idea of rhetoric in science in (Golinski 2004 chapter 4) and a rejection of its possibility in (Gaonkar 1993).

sociology of knowledge The role of writing within the enterprise of science. Examples include the discussion of literary inscription in Latour and Woolgar, in which they identify 5 types of statement of varying degrees of facticity (Latour and Woolgar 1979 pp75-88); the idea of virtual witnesses - 'We usually think of an experimental report as a narration of some prior visual experience' ... 'we should also appreciate that the text itself constitutes a visual source (Shapin and Shaffer 1985 p61); and the stabilisation of the concept of a quantitative measure of quality of life in the close reading of a health economics paper by a group of medical sociologists (Mulkay, Ashmore, Pinch 1987)

² See for example (Hacking 1975) (Surkis 2012) (Hirschkop 2019)

³ For a recent overview of some of field see (Willis 2015)

science studies Literary devices in scientific text; somewhat like rhetoric but looking beyond texts too. For example (Woolgar 1980) (Morgan 2017) (Hallyn 2000) . William Clark applied categories of narrative typology to well known history of science texts (Clark 1995).

literary scientific studies The diffusion of ideas from science into literature. The proceedings of the 1987 conference ‘Literature and science as modes of expression’ show, as the editors point out, that the direction of travel is mostly from science to literature. (Amrine 1989) - for example Sally Shuttleworth describes Victorian ideals of masculine power as originating in scientific discourses of energy regulation and brain function. ‘Medical theories of nervous disorder’ she writes ‘and the workings of the female body feed through, in various forms, into virtually all the fiction of the period.’ (Shuttleworth 1996 p6) ; counternarratives of germ theory in late nineteenth century novels (Nixon 2020). (Kahn 2020) might be seen as a counter example, in which the literature of a period raises questions about what counts as evidence.

historical studies Studies of the materiality of discourse building - of the way cultural values and social interests shape the content and expression of science. Examples include the link between politics and phrenology (Shapin 1979); a history of statistics in Britain, in which social interests can be seen informing the construction of the contingency table (MacKenzie 1981); about the science of hormone research Nelly Oudshoorn writes ‘biomedical discourses, however, not only are shaped by technological developments, but also shift in response to changes in society. The very words used to capture the complexities of the body show a changing set of metaphors that reflect the values of a specific historical period ‘(Oudshoorn 1994 p5); Ann Shteir discusses the changing format of botanical writing as it moved from a female/narrative form to a male/scientific form by 1830 (Shteir 1996); James Zappen explores the changing understanding of Bacon’s rhetorical style (Zappen 1989). Also (Jordanova 1992) (Raphael 2017) (Adam 2020). Paul Forman’s work on Weimar culture and physics might be included here although, unlike MacKenzie he does not discuss texts (Forman 1971). For a historical account of the role of science in shaping culture see (Gaukroger 2020).

cultural studies Studies of the common cultural origins of science and art, and of what Gillian Beer called, in her groundbreaking study of the assimilation of evolutionary themes into nineteenth century novels *Darwin’s Plots* ‘the to and fro of ideas, myths, metaphors, and narrative patterns.’ (Beer 1983 p5); Janis McLaren Caldwell’s study of the common formation of both scientific medicine and romantic literature, which, she writes ‘yielded innovations in both medical diagnostics and literary representation. Clinical practitioners developed the two-part history and physical exam, tolerating the tensions between the patient’s narrative and the evidence of the body. Literary writers

produced potent myths like *Frankenstein*, *Sartor Resartus*, and *Wuthering Heights*’ (Caldwell 2004 p1). Tita Chico characterises early science as a form of literary knowledge (Chico 2018), and Frederique Ait-Touati describes ‘a poetics of the credible in literature and in natural philosophy’ (Ait-Touati 2011 p11). Many other examples (Harre 1990) (Clark 1995) (Shuttleworth 1996) (Schleifer 2000) (Jenkins 2007) (Hopwood 2015) (Hyman 2017) (Crossland 2018) (McCutcheon 2018) (Tate 2020). There is also a branch of study looking at how the use of narratology could be used to improve the teaching of science in schools (Norris 2005); and a wide range of studies about narrative in medicine (Greenhalgh 1999).

A literary turn in philosophy

(Dear 2001) was concerned with the history of science rather than its philosophy. But what can be called a literary dimension has become important to the philosophy of science too. The importance of language to the philosophy of science is clear in the work of Mary Hesse, one of the most significant figures in twentieth-century history and philosophy of science⁴. This passage for example, might have come from the literary critic Gillian Beer:

Another example of cultural evaluation of theory in natural science may be taken from biology. In choosing as objects of study primarily the stable configurations of matter that form organisms and in concentrating on evolutionary sequences from "lower" to "higher" organisms (both terms are ascriptions of value), the biologist is guided by the significance of just these phenomena for understanding the place of human beings in nature. (Arbib and Hesse 1986:177)

Language runs to every part of philosophy in the twentieth century, analytic or otherwise.⁵ Why is this? ‘I have one answer to the question of why language matters to philosophy now’ wrote Ian Hacking in 1975. ‘It matters for the reason that ideas mattered in seventeenth-century philosophy, because ideas then, and sentences now, serve as the interface between the knowing subject and what is known’ (Hacking 1975 p178). The linguistic turn in philosophy isn’t so much the question of how representation works, but that representation is an issue at all, as Hacking suggests, and van Fraassen’s programmatic outline conveys□

⁴ Hesse - ‘The understanding of metaphor therefore poses a radical challenge to contemporary philosophy’ (Hesse 1988)

⁵ ‘The study of grammar is capable of throwing far more light on philosophical questions than is commonly supposed by philosophers’ Bertrand Russell in *Principles of mathematics*, 1903. Quotation appears in (Luton 1965) Further discussion on Russell’s linguistic philosophy in (Green 2007). ‘Truth is not a property of reality, but of representations’ (Agazzi 2017 p4). Hacker: ‘The second feature of the analytic movement in the twentieth century is the intense interest in, and meticulous attention to, language and its uses’. (Hacker 2007:129)

‘Science is a representation of *something*, in a *certain form of* language (by people speaking or writing *in a certain way*), accomplishing *by certain means* an *end or aim proper to this activity*. ‘ (van Fraassen 2007)

The linguistic turn in the philosophy of science⁶ was initially a turn *away* from actual language, an attempt to purify it into symbolic logic, into meaningful and non-meaningful categories, into forms of words which can only be either true or false.⁷ But, as Peter Hylton observes, transforming even a very modest sentence such as ‘my teacup is empty’ into a logically perfect language is a difficult undertaking (Hylton 2007:100). Increasingly the linguistic turn was *towards* structures within ordinary language that could bear the weight of philosophical enquiry. These include: protocol sentences, which provide an appropriate structure within ordinary language for the evidence statements of both institutionalized science and everyday speech (Nottleman 2006); a more semantic conception of truth and possible languages which utilise it;⁸ the assertion that sentences have meaning only in reference to a larger body of knowledge (Quine 1951); the claim that observation sentences are loaded with theory within their linguistic structure (Hacking 1993 p171); and Popper’s World 3, the world of both science and language (Editors 2013). All are evidence that language became both the problem of and the solution to epistemology in the twentieth century for the reasons Hacking described.

Fictionalism and model based science

According to Bradley-Garb, *fictionalism* can appear in almost any zone of philosophy (Armour-Grab and Kroon 2020 p1). Fictionalism is an upper limit to the linguistic turn in philosophy. ‘According to Eklund’, Bradley-Garb continues ‘[fictionalism] about a region of discourse can provisionally be characterised as the view that claims within that discourse are not best seen as aiming at literal truth but are better regarded as a sort of ‘fiction’’ (*ibid* p6) In other words, the sort of realism Cartwright argues for in a series of works beginning with (Cartwright 1983).

‘Fictionalism in the philosophy of science emerges from the style of science known as model based science’ (Armour-Grab and Kroon 2020 p13). The best modern philosophical explanation for the distinctiveness of science is not as their embodiment of law-like assertions or a method (induction/deduction/experimentation/hypothesis testing etc) but as a symbolic structure, a model. As with fictionalism, models do not

⁶ The distinction between syntactic and semantic models of science, reviewed by (Lutz 2015) and in the introduction to (Frigg and Hunter 2010), takes place within a conception of knowledge rooted in language rather than ideas.

⁷ Wittgenstein in 1929: ‘The syntax of ordinary language, as is well known, is not quite adequate for this purposeThe idea is to express in an appropriate symbolism what in ordinary language leads to endless misunderstandings’ (Wittgenstein 1993 p29).

⁸ ‘We can imagine the construction of languages which have an exactly specified structure without being formalized [as deductive logic]’ (Tarski 1944)

need to be inherently true or false, but more or less effective (Cartwright 2019), whether they are abstract or real (Sterratt 2002).

Models are the literary turn in the philosophy of science.⁹ Their components include mathematical notations; idealisations, described by Woods and Rosales as statements known to be false (Woods and Rosales 2010); and fictives, once considered by philosophy to be the same thing as error, blind alleys and confusion (Boodin 1943).

Idealisations and fictives have the philosophically troubling property of not existing except as language; of being in truth neither real nor true, or at least strange enough to revive an interest in the philosophers Hans Vaihinger ‘whose general concern is with fictional elements in human thought’ (Fine 1993) (Suarez 2009) and Alexius Meinong, whose ‘often quoted... “*There are objects of which it is true to say that there are no such objects*” stands in stark contrast with conventional classical logic and extensionalist existence-presuppositional semantics.’ (Jacquette 2015).

Fictionalism in philosophy may or may not be usefully analysed as literary fiction. The sentences in works of fiction are considered by John Woods to be neither true nor false since they have no reference (Woods 2018 p3). If one characterises models in this way they might have some resemblance to a literary fiction and perhaps literary theory may cast some light on the role of models in science (Salis 2019). Woods has some misgivings about such a project (Woods 2019), discussed in section 1.4 of this paper.

What sort of literary dimension?

When Peter Galison asked, in *Ten problems in the history and philosophy of science*, ‘what is the toolkit of argumentation and demonstration’ (Galison 2008) he did not include any sort of literary theory. But the partial list of recent scholarship above shows that much of the most interesting work in science studies today involves an encounter with text, requiring what might approximately be called literary studies, more accurately an analysis of the interplay of documents and text with their producers and readers, and their circulation in the scientific and wider culture.

However, none of these areas of study - most notably rhetoric and linguistics but to some extent also philosophy which focuses on certain elements of narrative - appear to contain an explicit theory of scientific narrative. Gopnik discusses frequencies, patterns, normalisation between texts, and syntactic structures, with a view to establishing ‘a computable underlying form’.(Gopnik 1972 p9). Philosophers, based on what they regard as the misrepresentation at the heart of fiction, focus on problems of ontology and representation (Kroon and Voltolini 2019). Alan Gross applies classical rhetoric to

⁹ There is by now a significant body of writing about models for example (Morgan and Morrison 2009) (Hartmann 2009) (Suarez 2009) (Frigg 2010b) (Toon 2012) (Frigg and Hartmann 2020)

science; he discusses analogy, style, and the possibility of complete rhetorical description of science. He asks ‘*can a rhetorical hermeneutic, or a way of reading texts as rhetoric, be anchored in coherent and enabling theory?*’ (Gross and Keith 1997 p1), answering that the theory will emerge from examples.

In this paper I want to propose a coherent and enabling theory-model of narrative in science, based on the purposeful representation of fictional narrative outlined by Roland Barthes in 1966 and described in more detail in 1970 and 1971 (Barthes 1966, 1970b, 1971b). The purpose is twofold. Firstly, to show that scientific writing follows the same rules of construction as other narratives. Secondly, to examine how, within a common framework, scientific narratives differ and are distinct. The hypothesis of this paper is that, despite their differences, scientific texts and a short story are instances of narrative, of storytelling in the best sense of the word.¹⁰

Questioning the value of textual analysis in science

Although superficial similarities might be accepted, the idea that at a deeper level storytelling and science have commonalities is troubling. ‘Until now’, write Morgan and Wise, ‘philosophers of science have not given narrative much credence as having any epistemological functions and, if anything, have been deeply suspicious that it could have any such functions’ (Morgan and Wise 2017).

Language, from the point of view of science, should be transparent, weightless; its content everything, its verbal form nothing. ‘If there is one feature’ wrote Evelyn Fox Kellner ‘that distinguishes scientific from other communities, and that is indeed particular to that special discourse, it is precisely the assumption that the universe scientists study ... is unmediated by language’ (Fox Kellner 1992 p28).

There might therefore be severe objections to the idea that there is anything of much interest to learn from the textual analysis of scientific writing. By way of an introduction to narrativity in science I address some of these objections now, which include:

- [Scientific writing isn't narrative](#)
- [Science is more than its written form](#)
- [In particular, the use of mathematics makes narrative analysis impossible](#)

Scientific writing isn't narrative - realism, language, models, fictionalism

In a time when everything is a narrative it can seem uncontroversial to say that science is too (Ryan 2007).¹¹ But what if scientific writing is anti-narrative; if calling it narrative

¹⁰ Yet, you know very well that a poem and a scientific report seem to have been produced by beings inhabiting different planets (Reeves 2005 p7).

¹¹ There is a field of educational research dedicated to exploring the benefit of translating science into narrative. For an example see (Engel 2018).

is to fail to understand its essential characteristic, it's realism? Despite Peter Medawar's assertion that scientific articles are politely fictionalised accounts (Medawar 1962), the intuitive, abiding and seemingly decisive difference between science and art, between scientific and imaginative literature is a commitment to realism, which would seem to put it at odds with the idea of narrative or any sort of literary theory (Norris 2001). An ability to Invent characters can win a novelist prizes. If the people in a scientific study are invented its author will never work again (Usman 2006).

Realism

Scientific realism, writes Hacking, 'says that the entities states and processes described by correct theories really do exist'. And, he continues 'even where our sciences have not yet got things right, the realist holds that we often get close to the truth' (Hacking 1983 p21). Modern science is one of humanity's greatest cognitive achievements (Elgin 2017 p8). Realism might be called the innate philosophy of scientists who, Bachelard writes 'have an immediate advantage over adversaries because, they believe, they have a hold on reality and possess the riches of reality while their adversaries, the mind's prodigal sons, chase empty dreams.' (Bachelard 2002: 136). 'What reality is like' writes WV Quine 'is the business of scientists, in the broadest sense, painstakingly to surmise; and what there is, what is real, is part of that question' (Quine 2013: 20-21). In contrast, however accurate their narrative - James Joyce prevailing on his friends for details of Dublin's streets for his novel *Ulysses*; the character Grace in Margaret Atwood's novel *Alias Grace* is based on the real person of Grace Marks - the realism of fiction comes from the pleasures taken in imagined worlds.

If something is **real** it can be said to exist independently of the knowing subject - **objectively**, as a fact; if it is objective it can be counted, can be subject to **quantification**, which provides empirical data, evidence. A kind of logical circuit therefore connects realism, objectivity, and quantification. Real things can be counted (or measured); things that can be quantified are trustworthy, mind-independent - are real (Porter 1995).

Hidden variables are real; IQ is real; straight lines are real; hyperbolic geometry is real; Quality of Life measures are real; electrons are real; quantum fields are real; populations are real; confidence intervals are real; fMRI scans are real; the block universe is real; time is real; tables are real. As these examples imply, a consensus definition of realism is hard to come by. Within the philosophy of science today there are well argued positions for realism, non-realism, quasi-realism, and constructivist-empiricist realism. The non-reality of mathematical objects is quite well established (Leng 2010). van Fraassen and Cartwright argue in different ways that there can be knowledge about the world without assurance that the objects of which there is knowledge exist. 'It is perhaps only a slight exaggeration' writes Anjan Chakravartty 'to

say that scientific realism is characterized differently by every author who discusses it' (Chakravarty 2017).

The question of realism is alive for scientists too. If experiments describe real objects the experiments should be replicable. But they often appear not to be.¹² In its own way, the so-called replication crisis in science is a literary crisis - what if the sentences in scientific papers have no referent, no signified. What if they were just words on a page?

I will take as my guide to realism in science the work of Nancy Cartwright. Partly because it helps develop the argument I want to make, but also because of its sustained engagement with the varieties of realism, its acknowledged prowess, and also because in a way her work, particularly *How the laws of physics lie* (Cartwright 1983) is a more sophisticated version of Medawar's essay.

Language

The linguistic turn affects the way the philosophy of science thinks about realism. The old way was to describe the realism of science as connected to discovering, developing, and testing scientific laws. Ideally, since Galileo, written as mathematics. For Kant, the possibility of scientific knowledge was connected to mathematics. 'In any special doctrine of nature' he wrote, 'there can be only as much proper science as there is mathematics therein' quoted in (Watkins and Stan 2014). But in the twentieth century, the question of realism is complicated by the growing need to deal with language. Where realism, at least in science, was guaranteed by mathematics, it is now mathematical and linguistic. Where scientific knowledge could once be summoned through mathematics and logic alone, it now has to pass through language too, as analysts as widely dispersed as Carnap¹³, Fleck and Hesse demonstrate. In the twentieth century there were two directions that accounting for language in the philosophy of science could take. One is to purge it of ambiguity, convert it to symbolic logic. The other is to build out from its lived materiality. Which means dealing with problems such as reference and meaning, the difference between word and object; with the possibility that what we call realism is not a property of the world but a property of sentences, and that reference plays no essential role in explaining the relation between language and reality (Davidson 1977).

Cartwright believes in realism and truth in science (she is not a relativist or a social constructivist). But she locates realism and truth in the interface between the powers (which might be also be called capacities and dispositions) of nature and the human capacity to make sense of them in symbolic representation:

¹² <https://www.nature.com/collections/prbfkwmwvz> The problem of replication is discussed in (Collins1985). Also known as a reproducibility crisis and interestingly is described by Fanelli as a narrative (Fanelli 2018). See also (Fidler 2018).

¹³ Carnap 'There is a common language to which both the biological and the physical laws belong so that they can be logically compared and connected.' Quoted in (Suppes 1993 p42)

'a very great deal of our important scientific knowledge is knowledge-how not knowledge-that; that, concomitantly, many of our most useful principles (including high-level 'laws' of physics) are neither true nor false but are rather (in the words of Pierre Duhem) 'symbolic representations' that we use to model, predict, and navigate the world; that a good many of these symbolic representations are short-hand labels for powers and our practices for using them; that our scientific successes do not suggest that Nature operates by 'law' in fixing what happens; rather the world is full of possibilities and what happens is best recouped by artful modeling.' (Cartwright 2019)

I understand this - it comes from the introduction to the Carus Lectures of 2017- to mean that truth in science is not theoretical. That is, it is not biddable by a logical framework for determining the correctness of scientific statements. What we call the laws of physics, Cartwright is saying, are neither true nor false but the consequential effect of dealing with nature the artful modeller as she calls it.

The idea of nature as an artful creation isn't new. Galileo argued for the existence of two books written by a higher power. Both works of truth, one is the Bible. The other is nature, which is written in the language of mathematics:

'Possibly he thinks that philosophy is a book of fiction by some writer, like the Iliad or Orlando Furioso, productions in which the least important thing is whether what is written there is true. Well, Sarsi, that is not how matters stand. Philosophy is written in this grand book, the universe, which stands continually open to our gaze. But the book cannot be understood unless one first learns to comprehend the language and read the letters in which it is composed. It is written in the language of mathematics, and its characters are triangles, circles, and other geometric figures without which it is humanly impossible to understand a single word of it; without these, one wanders about in a dark labyrinth.' (Galileo Galilei 1623)

We no longer believe, as Kant did, that science must be mathematical, or are as certain as Galileo that mathematics is true. But in any case, for the reasons Hacking set out (Hacking 1975), it is inevitable that our understanding of what constitutes science now includes the other great symbolic system, language.

Models

The best description of science today is that of a model, and the most interesting philosophy of science concerns what models are and how they work. This is because, as Frigg describes (Frigg and Hunter 2010: 98-99), the word model describes a range of objects (physical models, mathematical models, conceptual models etc), it forms a bridge between philosophers and scientists (many scientists would be happy to concede that what they do is create and test models), and is a shared metaphor suggesting the

presence of something else (reality) and a relationship between models and reality (representation).

There is of course no consensus among philosophers about what models are or how they work. Axel Gelfert provides a reliable guide to the variety of models (Gelfert 2006). Gelfert does not refer to the linguistic turn in philosophy, but whether syntactic, semantic, or pragmatic, models reconfigure the foundational questions of the philosophy of science as questions that must encounter language, as in Carnap's programme to develop a universal language of science (Leitgeb and Carus 2020) and the characterisations of science in (Hesse 1963), (Giere 1999), and (Cartwright 2019).

For the purposes of this essay the programme described by Peter Godfrey Smith in 2006 is particularly resonant:

A model, basically, is a set of objects (and relations between them) that functions as an interpreting structure for a set of sentences.When models are treated in this way, they can be used to help us understand any theories, any sentences, perhaps any representations with indicative content at all. They can be used to think formally about scientific theories, and they can be used to think formally about the sports pages of the New York Times. What we have here is a general way of thinking about meaning; we think about the meaning of a representation by thinking about the formal characteristics of structures that the representation can be seen as true of. (Godfrey-Smith 2006:727)

He goes on to say that philosophers have wanted to think of models as abstract mathematical constructions. But this has been principally, in his view, to avoid resurrecting Meinong's philosophy of abstract objects; this is not, he believes, a sufficient reason. Since both scientific models and fictional literature are populated by things that exist as symbolic languages but not philosophically speaking in the external world - ideal planes, infinite populations, Sherlock Holmes, Don Quixote, Gilead, Llaeggub - then model based science and literary fiction may have things in common:

Although these imagined entities are puzzling, I suggest that at least much of the time they might be treated as similar to something that we are all familiar with, the imagined objects of literary fiction. (ibid:727)

Fictionalism

The philosophy of fiction has little in common with literary theory because its main aim is to address the potential havoc of including non-existent objects, things that aren't true, in philosophy,¹⁴ so discusses literature in terms of epistemology, ontology, and representation (Kroon and Voltolini 2019) (Friend 2007) (Woods 2018). And if science,

¹⁴ Van Fraassen: 'no concept which is essentially language dependent has any philosophical importance at all (Van Fraassen 1980 p 56).

and scientific literature, is in a sense fictional, then the same problem - of fictional entities at the heart of science - applies (Frigg 2010b) (Suarez 2016) (Friend 2019).

John Woods is not entirely sceptical about the philosophy of fiction. But he is concerned by the logical inconsistencies in literary fiction,¹⁵ critical of much of fictionalism,¹⁶ and deeply sceptical of the potential for literary theory to add to an understanding of models in science unless that theory is logically well founded:

In some quarters, it is casually put about that an enlarged understanding of how scientific theories of nonexistent entities manage to enlist the doxastic support of serious and well-informed people might be obtained by modelling the scientific theories in (or on) “our best” theories of stories. But in the absence of a detailed command of the data that motivate story-theorists to provide a cohesive and unified account of them, any such modelling aspiration is a risk-laden prospect for any science that countenances the unreal. (Woods 2019:344)

‘Some philosophers’, he writes ‘have scorned any hook-up with literary fiction. Literary fictions, they say, are trifles, the subjects of our recreational amusements when we’ve found time to pause from our engagements with truly important things - quantum computing, the 5G race, that sort of thing.’ Despite the ‘systemic inconsistency of fiction’ and the ‘semantic and epistemic vacuity of literary discourse’ (vacuity here means, I think, lack of referent rather than vacuousness) Woods thinks it might be possible to rescue something if the philosophy of fiction grounds itself in empirical evidence, though the empirical evidence has to meet a very rigorous standard.¹⁷ The (from a logicians point of view) lies in Cartwright’s models are acceptable to Woods because he says, their intent is benign and because her logic exists outside the realist/anti-realist binary. He thinks that pretendism, the dominant theory of philosophical fictionalism, and even his own theory of a naturalized logic of fiction, set out in (Woods 2018), are unworthy, as he puts it, as ways to describe science.

Woods considers the asymmetries between philosophy and literary theory, as he sees them, including the limitation of what he calls the systemic inconsistencies of fiction. He believes that literary theory has more to gain than philosophy from a dialogue

¹⁵ “‘The nub of fiction’s most distinctive semantic problem is that every sentence of [Arthur Conan] Doyle’s text is concurrently true and not true, yet safe from cognitive turbulence by a distinction that imparts no ambiguity. On the face of it, this should not be so. Every untutored literate human being knows that it is impossible for something to be unambiguously true and not at once.’ (Woods 2019:359)

¹⁶ ‘Fictionalism is best seen as a species of scientific unrealism which tries in some slight way to compensate for what the entities of unrealist science really aren’t (namely real) by finding something that they really are (namely fictions). We could fairly wonder in what the hoped-for compensation would consist, and how anything unreal could have the property of being something.’ (*ibid*:339)

¹⁷ Evidence ‘is good when it is accurate and up-to-date, and is well-filtered when it is unmolested by noise, by quantities that overload processing capacity, by distortive irrelevancies, by unproductive, by wheel-spinning inconsistencies or by the smothering ignorance’ (*ibid*:350)

between them. He concludes with a call to a programme of creative realism, ‘a realism that grants full membership to humanly created things’ (Woods 2019:367).

It is not especially fruitful to map the realism of models - a realism that grants full membership to humanly created things - to fiction, pretendism, or make-believe. Projecting some foundational issues in epistemology and ontology onto literature, and onto art more generally, creates what is a purposefully narrow sort of literary theory, but it is narrow nonetheless, as the essays in (Bueno 2018) discuss.

The difficulties that arise could be caricatured as arising from the fact that the aim of art is not to help solve certain problems in philosophy. ‘A truth-centered, or veritistic, epistemology’ writes Catherine Elgin, ‘must treat models, idealizations, and thought experiments as mere heuristics, or forecast their disappearance with the advancement of scientific understanding’ (Elgin 2017:1). The starting point for the sort of analysis Elgin wants is narration, narrative, language in use (Cartwright 2010). This is because models are not representations but the performance of reality in symbolic language.

The argument in this paper is that narratology of some sort has a role to play in the cultural, political and social studies of science. If science is not simply about representing reality, narrative is not simply about story-telling. As Kate Hamburger argued, to equate narrative with make-believe is to discount what she called the narrative function in the logic of literature (Hamburger 1957). Narrative is more like a strategy of explanation and it might be better to speak of a narrative of fiction, a narrative of history, a narrative of science, and so on, each of which embodies in their own ways White’s characterisation of narrative as having three functions: firstly a bare recounting of events; secondly confirmation that these events happened; and thirdly, through explanatory effects, persuasion that these events have some significance (White 1972). And within literary theory, the most complete account of narrative is that of (Barthes 1970b), discussed in the next section of this paper.

Science is more than its written form

When Peter Medawar told listeners to the BBC in 1963 that scientific papers were a fraud he didn’t mean, he explained, that they were deceptions, but that they misrepresent the processes by which scientific conclusions were reached. Scientific papers are sometimes fraudulent, but they are often a polite re-staging of events so that scientific practice might appear to conform to an ideal of inductive logic (Medawar 1963).

Medawar was highlighting two things. Firstly, because of the gap between the reality of science and its authorised texts, that there may be something interesting in the construction of scientific texts themselves (Woolgar 1980). And secondly, that the reality of science is not fully present in its texts. Science is also the conduct of scientists, a culture as Pickering observed (Pickering 1995 p4), including organisations

and networks, the relations between teams of researchers, the impact of scientific results on society, ethics, rationality, and a social epistemology. None of which are visible if analysis remains purely at the level of scientific papers. So it might be that the detailed analysis of scientific text is the wrong target, or an over-expenditure of effort, and that the yield is less than the effort required.

A complete reading of a science would include its wider economy, which itself sits in an overall culture.¹⁸ But even so, scientific papers would remain important artefacts, positive expressions of the culture from which they emerge including the erasure of that culture. The purpose of this paper is to systematically break open scientific writing in order to show the points at which it connects to culture.

The presence of maths is a critical difference between scientific and non-scientific texts. Mathematics is a distinctive language; its presence a key distinction between scientific and all other forms of knowledge, the starting point and end-point of rigorous knowledge.¹⁹ The question of mathematics in cultural analysis of science is therefore important, but it is difficult to deal with. For critics, Mary Poovey observed ‘numbers constitute something like the last frontier of representation’ (Poovey 1998 p xi).

Mathematics is at the same time fundamental to cultural analysis and outside its bounds because it is unreadable²⁰:

- almost every scientific text will include some mathematics while few literary texts do. Literary analysis has had little need to encounter mathematics²¹, even if there are stories based on mathematical ideas; mathematical structures latent in works of fiction (Drozdz 2015); narrative structures in mathematical papers (Kamareddine 2007); and a deep relationship between modernism and mathematics (Gray 2008)
- mathematics is a language barely spoken except by specialists. It cannot be translated, and so remains largely inaccessible to literary analysis
- any appearance of mathematics in a text is linked to fundamental operations in our culture - to realism, and that the world may be understood in an orderly way.

¹⁸ And scientific practice, as Rouse writes, may be structured like a narrative: ‘the intelligibility, significance, and justification of scientific knowledge stem from their already belonging to continually reconstructed narrative contexts supplied by the ongoing social practices of scientific research.’ (Rouse 1990).

¹⁹ Kant: “in any special doctrine of nature there can be only as much *proper* science as there is *mathematics* therein” quoted in (Watkins and Stan 2014)

²⁰ Mathematics puts in a brief appearance in S/Z as ‘an ideally pure message’ (p145), and as ‘the violence ...of ‘pre-demonstrative nomination’ (Barthes 1970b:130) In other words, Barthes is no help at this point because he is speaking about maths from the other side, from the side which sees maths as pure message in contrast to the plural messages of literary texts.

²¹ For an overview see (Jenkins 2017) and the introduction to (Englehardt 2018).

Whatever distinction we may give to maths in an analysis, it is also true that mathematical arguments themselves may have a literary structure (Netz 2009) and, as Henk Bos has argued, mathematics is incompletely understood by its practitioner, its concepts are fluid, and the truth of its primary objects is not safeguarded by logic (Bos quoted in Cifoletti 2006) , which makes maths accessible in principle to forms of cultural analysis.

In his study of the philosophy of mathematics Hartry Field asked four questions, and answering them is a way to clarify the approach taken in this paper. He asked the following questions (Field 1980 pi):

- a) How much of standard mathematics is true?
- b) What entities do we have to postulate to account for the truth of mathematics?
- c) What sort of account can we give of our knowledge of these truths?
- d) What sort of account is possible of how mathematics is applied to the physical world?

His own answers are that mathematics can be true and good and useful without needing to believe in the reality - which he calls true - of external mathematical entities:

Questions (a)–(c) are thus trivially answered: no part of mathematics is true (but you can use impredicative reasoning and other controversial reasoning all you like in mathematics as long as you're pretty sure it's consistent); consequently no entities have to be postulated to account for mathematical truth, and the problem of accounting for the knowledge of mathematical truths vanishes. (ibid pii)

And his answer to d), which he regards as the fundamental one²², is simply that mathematics has to be applied consistently.

The same questions could be put to non-philosophers - to the scientists who use maths, the readers of scientific papers, and the analyst of scientific text. The answers would be similar to Hartry's, except for the last question. They might plausibly run as follows:

- a) The mathematics in a scientific paper is assumed to be true, in the sense that the numeric values are accurate, and that any mathematical operations - statistical tests such as the chi-squared test for example - are accepted among peers as meaningful and correctly applied. Aspects of the truth of the mathematics in a scientific paper may be contested, especially in statistics (Hogben 1957) (Howson and Urbach 2006) - for example, is a p value of 0.05 justified? Are Bayesian statistics better in some way than frequentist statistics? At the extreme the numeric values in a scientific paper might be

²² Einstein is famously quoted as saying that the great puzzle is how mathematics, a free invention of humans, seems to apply so well to nature. See (Clark 2017 p4)

contested, as they were in Cyril Burt's study of IQ (Gillie 1977). There is also a vexed question, for scientists at least, of reproducibility, in which identical experimental set ups may not produce the same empirical results (Collins 1985).

b) There are no entities, other than the entities that are the symbols and the arithmetical notation, required. From a linguistic point of view, the beguiling feature of mathematics is that it is both signifier and signified.

c) No account is necessary. The majority of scientific papers make use of mathematics, and assume that its truth is given. There are scientific papers whose purpose is to prove the truth of certain mathematical theorems and puzzles. And there are accounts of mathematical discoveries, including those which consider mathematics to be socially constructed in some way (Bloor 1976) (MacKenzie 1981).

d) Mathematics is applied to the real world through its use in models.

For scientists the account of how mathematics is applied to the real world is seen in the correctness or at least the acceptability of the model, measured in terms of its ability to produce plausible results. A clinical trial is a mathematical model, which is set up to answer questions about the effectiveness of therapeutic drugs. It is populated by human subjects, randomly allocated to receive a test or a control treatment, who provide numeric data which is collated and analysed mathematically to produce quantitative data about the effectiveness and safety of the therapeutic intervention being tested. From the perspective of - in Dear's sense - literary studies of science, mathematics is a narrative strategy; it is part of the way in which the authors persuade the audience about the reality of the research, the objectivity with which the research is undertaken and the meaningfulness of results it produced.

Bueono and French ask 'But if mathematics is being used, what are the moves that allow us to justify our lack of commitment to mathematical entities?' [Bueno and French 2018 p153] The rather simple answer I want to propose is that the vivid sense of reality required by (Rabinowitz and Vogel 2009) is an emergent property of a scientific paper, and that maths figures strongly in this. An example is this fragment of a scientific paper from 2013:

A genome-wide association study of educational attainment was conducted in a discovery sample of 101,069 individuals and a replication sample of 25,490. Three independent SNPs are genome-wide significant (rs9320913, rs11584700, rs4851266), and all three replicate. Estimated effects sizes are small ($R^2 \approx 0.02\%$), approximately 1 month of schooling per allele. A linear polygenic score from all measured SNPs accounts for $\approx 2\%$ of the variance in both educational attainment and cognitive function. Genes in the region of the loci have previously been associated with health, cognitive, and central nervous system phenotypes, and bioinformatics analyses suggest the involvement of the anterior caudate nucleus (Rietveld 2013).

The object text, which finds a degree of association between a person's genetic constitution and their educational success, might be studied from a sociological or cultural perspective, but that would be a different elaboration of the argument I want to make. Nor do I want to contest the findings of this paper, though they are contestable of course.

What anchors the language of this text in reality? Two things. Firstly the nouns, or facts - genome-wide association study, phenotype, cognitive function, and so on. And secondly the numbers, 9320913, 0.02%, 101,069, 1 month. The numbers especially correspond to White's three functions of narrative. Firstly numbers provide a direct recounting of events. To say that 101,069 individuals were included in the discovery sample is a precise denotation, and a connotation of actuarial precision. It probably does not matter much for the science if the actual number of people was 101,070, or even 101,100. But what matters, what produces meaning at this point, is the sense of accuracy, of reckoning, of counting. The number adds to the sense 'this is real'. Secondly, a specific number suggests that this enumerative event happened, it provides the reader with a warranty, or at least the suggestion of a guarantee that if the reader wanted to they could consult study records to confirm for themselves that the number is accurate. Numbers are seemingly trustworthy indexes of the real - rs4851266 refers to a record in a database of variation in human DNA sequence at specific locations²³. And the third part of White's narrative function, argument, persuasion that these events have some significance, can be seen in the numeric estimates of effect size. R^2 0.02% is a statistical measure of the correlation between two sets of data, and the figure 0.02% means that in a model where genetic variation was associated with educational attainment 0.02% of the data points fit the model. A lot could be said about such low values,²⁴ but my intention is simply to mark the occurrence of mathematical calculations in a text.

Together the notations in this fragment of text create something like a *reality effect*, to suggest the similarities to the role played by detail in the nineteenth century realist novels (Barthes 1968).

Some other things which show this text connected to reality (as opposed to it being fiction, invention) lie outside the text, including: the journal it was published in (Science, a long established, distinguished peer-reviewed academic journal); the number and affiliation of the authors (the paper has over 100 authors, any of whose careers would be damaged if the paper was seen to be a fraud); and the network of scientific papers that quote this one, thereby stabilizing its membership of the community of

²³ <https://www.ebi.ac.uk/gwas/variants/rs4851266>

²⁴ Toth B Conclusions of study on height, body mass index, and socioeconomic status have an uncertain basis. BMJ (Clinical Research ed.), 353:i1891, 05 Apr 2016

scientific knowledge

(<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3751588/citedby/>).

In applying the same logic to the analysis of nineteenth century realist fiction and a recent scientific text, the claim is not being made that the objects in a realist novel are real, nor that the objects in a scientific paper are unreal. It is possible, probable even, that one day GWAS science will seem as quaint as phrenology does today (Cooter 1984). But if something has a name, if it can be defined, can be measured, can form part of a testable proposition, can be referenced, and is consequential, who would then say it is not real?

The statistic R² - the coefficient of determination - which is used a great deal in recent human genome research, is based on the following calculation which is not shown in the text but assumed to be known and accepted by readers of the main text:

$$r = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{[n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y)^2]}}$$

The density, compactness, and complexity of formulations such as this make commentary difficult. Not pursued further here, this equation was established by Egon Pearson, and is discussed by Donald MacKenzie in his study of statistics and eugenics in early twentieth century Britain. MacKenzie argues that the different ways in which correlation might be measured were related to competing conceptions of heredity, eugenics, and the place of science in society. '[Pearson's] notion of correlation' MacKenzie writes, 'as a function allowing direct prediction from one variable to another, is shown to have its roots in the task that correlation was supposed to perform in evolutionary and eugenic prediction.' (MacKenzie 1981 p169) 'Pearson's point was essentially a political one: the viability, and indeed superiority to capitalism, of a socialist state with eugenically- planned reproduction. The quantitative statistical form of his argument provided him with convincing rhetorical resources, which he employed mercilessly' (MacKenzie 1981 p91).

The intention in this paper is less ambitious than MacKenzie was - it is simply to note, in passing, the function of particular instances of mathematical notation in the text. Clearly, to do this, the analyst needs some understanding of mathematics, but ultimately the mathematical notation is an integral part of the text - they are as assertions *within* the text which can operate as description, plot and argument. The more one looks the more tempting it is to conclude that a mathematical statement might be assigned to any of the narrative codes discussed in Section 4. Or to more than one simultaneously, which could be a recognition of the powerful linguistic role played by maths in

scientific papers. 'I can distinguish' writes Steven Shapin 'six senses in which Boyle either deployed mathematics in his experimental practice, explicitly approved of its role in the overall culture, or apparently commended it formally as having a central place in natural philosophy' (Shapin 1994:317).

Mary Poovey wrote (with apologies for the extended quotation; the boldening is mine):

I very gradually discovered ...that the combination of numbers and analysis in those early nineteenth century texts spoke to a philosophical conundrum that did not necessarily involve numbers at all.. 'Instead of exploring the historical meanings or uses of numerical representation, I needed to pose an epistemological question. I needed to ask how knowledge was understood so that it seemed to consist of both apparently noninterpretive (numerical) descriptions of particulars and systematic claims that were somehow derived from those particularized descriptions.

*Eventually I discovered that in most of the knowledge projects produced during the long period of modernity, the two functions that appear to be separate in those early nineteenth-century texts actually coincide. Indeed, I discovered that even in those texts the two functions only seem to be distinct, for what look like two functions-describing and interpreting-seem to be different only because one mode of representation (the numbers) has been graphically separated from another (the narrative commentary) . **I discovered that in those nineteenth-century texts, as in most texts that purport to describe the material world, even the numbers are interpretive, for they embody theoretical assumptions about what should be counted, how one should understand material reality, and how quantification contributes to systematic knowledge about the world. Such figures, which simultaneously describe discrete particulars and contribute to systematic knowledge, constitute examples of what I have called the modern fact.*** (Poovey 1998 p xii)

2 Roland Barthes and models of narrative

Roland Barthes

The French literary theorist and cultural critic Roland Barthes (1915-1980)²⁵ doesn't appear in the *Encyclopaedia of Literature and Science* (Gossin 2002), and only once, trivially, in the bibliography of the Society for Literature Science and the Arts 2001-2011²⁶. And while the title of Alan Gross's *Starring the Text* playfully makes reference to what Terry Eagleton called Barthes' astonishing study *S/Z* (Eagleton 2008 p119), Gross makes no further use of it. Nor does Robert Scholes, a leading American theorist of narratology in his 2006 synoptic overview of the progress of his subject since the 1960s (Scholes, Phelan. Kellog 2006 Chapter 8) And it is worth noting in passing the extent to which Barthes was cut-to-size in (Harris 2009).

This level of non-engagement is something of a lost opportunity. Throughout his career Barthes was concerned, systematically and in detail, with the relationship between rhetoric, science, and society, connecting language and the human relations it implies and employs [Stafford 2018]. *African Grammar*, an essay included in his first book *Mythologies* (Barthes 1957), exposes the colonialist rhetoric that is embedded in the popular press under the guise of journalistic objectivity (Brody 2012). The relevance of *The Rhetoric of the Image* (Barthes 1964) is obvious; between 1964 and 1969 he conducted five seminars on rhetoric, resulting in several publications including *The Old Rhetoric an Aide Memoire*, discussed in (Pino 2019); and the invocation of rhetoric in a late work on photography is striking. Especially telling for this essay is a statement of 1967 that 'only writing can break the theological image imposed by science' (Barthes 1967 p9). 'The role of literature' he continued 'is to represent actively to the scientific institution just what it rejects i.e. the sovereignty of language' (*ibid* p10). The potential for Barthes' work to reinvigorate the rhetoric of science seems clear.

Barthes is known as the author of *Mythologies* and an oracular pronouncement about the death of the author (Barthes 1957)(Barthes 1968b). As his biographer Tiphane Samoyault explained, these are significant outcrops of a twofold project that spanned his career, 'to analyse the major articles of mass consumption as languages, but also to read literature in a new way' (Samoyault 2017:456-7). *Mythologies*, his first published book, is based on a series of essays commissioned by *Les lettres nouvelles*, which exposed the half obscured meanings in the language of advertising and in everyday cultural objects such as steak and chips, soap powder, and the design of the new Citroen (Barthes 1957). Towards the end of his life (cut short in 1980 by a vehicle accident in

²⁵ Selected writing and introduction (Sontag 1982); Introductions to Barthes (Lavers 1982) (Eagleton 2008 p 116-19) (Culler 2002) (Allen 2003) (Sturrock 1998) (Macquillan 2011) (Trifonas 1997); Biography (Samoyault 2017)

²⁶ Online bibliography <https://bit.ly/2ZfunqM>

Paris that led to his death) he published a series of increasingly personal books which embodied, as he saw it, new ways for a text to offer itself to its reader: a fragmentary autobiography (Barthes 1975); a meditation on love (Barthes 1977); a highly personal theory-meditation on photography (Barthes 1980); and the mourning of his mother's death (Barthes 2009). And in-between, essays and books on how language generates meaning, including extended accounts of the science of semiology (Barthes 1964), what he called the fashion system (Barthes 1967b), a visit to Japan (Barthes 1970a), and the detailed analysis of a single text (Barthes 1970b).

The theoretical underpinning of his project changed over time. Simplifying his own scheme (Barthes 1975 p145) slightly, the first phase of his work, up to the mid 1960s, was informed by the effect of systems and structures on life and politics, by Saussure and structuralism. 'The object of this inquiry' he wrote in the preface to a study of fashion 'is a structural analysis of women's clothing as described by fashion magazines; its method was originally inspired by the general science of signs postulated by Saussure under the name *semiology*' (Barthes 1967b:ix). Secondly, distancing himself from the idea of a science of signs (Samoyault 2017:422) and reorienting his interest towards text, which became a keyword for the second part of his writing:

We know now that a text is not a line of words releasing a single 'theological' meaning (the message of the author-god) but a multidimensional space in which a variety of writings, none of them original, blend and clash. (Barthes 1968)

The rejection of what he came to regard as an overly scientific approach to his work, and a new direction for his writing, was set out in a programmatic essay *From science to literature*:

The task facing structural discourse is to make itself entirely homogeneous to its object: this task can be accomplished by only two methods, each as radical as the other; either by an exhaustive formalization, or else by an integral writing. In this second hypothesis (which we are defending here), science will become literature, insofar as literature - subject moreover to a growing collapse of traditional genres (poem, narrative, criticism, essay) - is already, has always been, science. (Barthes 1967a p10)

Then followed three book-length studies: *Empire of signs*, an experimental account of a visit to Japan (Barthes 1970a); *Sade, Fourier, Loyola* (Barthes 1971a)²⁷. The third book published around this time, *S/Z* (Barthes 1970b) manages to be what Barthes had argued in *From science to literature* was not possible - both science and literature as he meant

²⁷ 'The text is an object of pleasure' (Barthes 1971a p7) The work highlights the creation of meaning and order across three very different writers without interpreting and evaluating their finished works (Culler 2002 p38-39).

them, an exhaustive formalisation and an integral writing that inserted itself into the text of a short story by Honore de Balzac.

Structure, narrative, close reading, and S/Z

The idea that literature is structured in some way, and that it might be subject to close reading and detailed analysis was not new in 1970. In 1928 Vladimir Propp ‘reduced all folk tales to seven spheres of action and 31 fixed elements or functions’ (Eagleton 2008 p91). In the 1950s Kate Hamburger insisted on the role of narrative in literary theory (Hamburger 1957). For Northrop Frye, writing in 1957, literature was an autonomous verbal structure which contained various modes, archetypes, myths and genres. ‘At the root of literature lay four narrative categories, the comic, romantic, tragic, and ironic, corresponding to four mythoi’ (Eagleton 1980 p80).

Detailed analysis - methodical and close reading of texts - was a leading 20th century literary theory up until the 1960s. For the largely American school of New Criticism, close reading was simply the most scientific form of literary criticism (*ibid* pp38-46). And in other disciplines, history for example, Hayden White was developing a theory of the narrative structure of historical writing (White 1972). All of this traceable back to the grounding of critique, of philosophy, in linguistics, and the question, across all disciplines, of the connection between signifiers and signifieds.²⁸

S/Z (Barthes 1970b) is a 200 page analysis of a 13 page short story by Honoré de Balzac called *Sarrasine*, which recounts the events concerning an evening party in a Paris Salon in the early nineteenth century, and the relating of a story about the sculptor Ernest-Jean Sarrasine who tragically falls in love with the castrato Zambinella.²⁹

Probably the most detailed literary forensic analysis of a literary text, *S/Z* consists of three fundamental operations:

- the text of *Sarrasine* is broken into 561 fragments
- the presence within each fragment, of one or more of five narrative codes is identified and described
- the way these codes weave together to produce the text as a story forms the majority of the analysis.

²⁸ For philosophy see (Hacking 1975) (Dennett 1992). For political theory see (Nussbaum 1995); anthropology (Clifford and Marcus 1986); sociology (Reed 1989) (Green 1983); historical geography (Richards 1993). On Hayden White’s narrativist philosophy of history see (Paul 2011). For the linguistic turn generally see (Jameson 1972 chapter 1) For the spread of narrative analysis generally see (Hatavara 2013)

²⁹ The text of the story is published as an appendix to *S/Z*. A useful and critical introduction (Whitehead 1992) also (Garnett 2018 pp 63-67) and (Culler 1975 pp 221-269). The relationship between *S/Z* and the seminar that gave rise to it are discussed in (Badmington 2016:113)

The codes and the way they form a text are discussed below. The following examples illustrate the analysis of a specific fragments of text:

(202) *when he went one evening to the Teatro Argentina*, ★ ACT. “Theatre”: 1 : to enter (the building).

(206) *He entered* ★ ACT. “Theatre”: 2 : to enter the hall.

The description of each lexia follows the same pattern:

(Identifier) the text of the lexia ★ CODE1. Explanation. ★★ CODE2 explanation

The number in brackets refers to the number of the lexia in sequence from 1 to 561. The text itself follows, italicised. Some lexias are just a few words and others several sentences: lexia 411 is a single word, lexia 65 is 2.5 sentences. The capitalised term following the ★ refers to one of the 5 narrative codes. In (202) the proairetic code ACT, the code of action, is identified. In (202) the ACT code is the beginning of a sequence labelled Theatre. The second ACT code in the Theatre sequence occurs in (206).

Some lexias can contain more than one code. (463) contains the ACT code and the REF code (culture, reference code) :

(463) *but he had come in a travelling carriage drawn by powerful horses and driven by one of the most enterprising vetturini of Rome*. ★ ACT. “Kidnapping” :5: rapid means of escape. ★★ REF. Italianness (vetturini).

The five narrative codes

The narrative codes, under which all the textual signifiers can be grouped, are as follows; their description is based on Barthes’ own explication in an interview he gave shortly after publication of S/Z (Barthes 1970b) :

The **Hermeneutic** (HER) code covers the setting into place of an enigma and the discovery of the truth it conceals. In a general fashion, this code governs all intrigues.

The **Seme** (SEM) code is usually single words which, in addition to being signifiers as all words are, have the additional property of connotation - invoking associated and secondary meanings.

Symbolic (SYM) codes are related to semes but exist in a network rather than a single word. They are seen conventionally in rhetoric (for example antithesis, two directly contrasting terms placed together) or tarot (in which the symbolic structuring of cards is

used to infer meaning). Symbolic structures are open to substitution and variation, and like semes play a significant role in the multivalence of texts.

Proairetic (ACT) A term borrowed from Aristotelian rhetoric, which ensures that we read the novella as a story, a succession of actions. Actions can fall into various sequences which should be indicated merely by listing them, since the proairetic sequence is never more than the result of an artifice of reading; furthermore, since these actions produce effects, each effect will have a generic name giving a kind of title to the sequence, and we shall number each of the terms which constitute it, as they appear (ACT. "To be deep in": 1: to be absorbed) (Barthes 1970a:18) .

Cultural (REF) codes 'are references to a science or a body of knowledge; in drawing attention to them we merely indicate the type of knowledge referred to, without going so far as to construct (or reconstruct) the culture they express.

Assembling the codes

The codes are not latent in the text. 'We are' writes Barthes 'not concerned to manifest a structure, but to produce a structuration' (Barthes 1970b p 20) 'The five codes create a kind of network' Barthes writes, 'a topos through which the entire text passes...each code is one of the voices out of which the text is woven' ...'the convergence of the voices (of the codes) becomes writing'. (Barthes 1970b p18-19, 21). And the reading is as active a labour as the writing. 'I read the text' writes Barthes (Barthes 1970b p10), which he immediately complicates by describing reading as a similar activity to writing ('I write my reading'), a work of recovering meanings, which he stresses is also a work of assembling the subject who reads, more an act of interpretation than understanding. Finally, texts are in themselves neither objective or subjective: 'Objectivity and subjectivity are of course forces which can take over the text, but they are forces which have no affinity with it.' Both are imaginary systems, which the writer or the reader may bestow upon the text.

First published in French in 1970, and in English in 1974, *S/Z* was both a turning point in Barthes personal career and as a marker of the transition from structuralism to post-structuralism (Eagleton 2008 p116). The innovation in *S/Z* was twofold. Firstly, the microscopic level at which the five narrative codes were located in the text. Secondly, despite appearances, the purpose of the analysis was not to interpret, comment, or add meaning to the text of *Sarrasine*, but show how it produces meaning. This purpose was reflected in the relationship between the codes and the text. Barthes made it clear in his introduction that he was not, as Frye was, trying to 'extract from each take its model, then out of these models make a great narrative structure' (Barthes 1970b p3). Instead, Barthes was interested in the plurality of meaning that texts have for readers, and in particular the ways this plurality is generated and sustained.

The method in *S/Z* follows from Barthes' interest in plurality. Firstly, any text will do. If all texts are more or less plural, then any text can form the subject of analysis 'the single text is valid for all texts of literature' (*ibid* p12). Secondly, there is no redundancy - all the parts of the text have a narrative function in one way or another. Thirdly, the relatively macroscopic features encountered as the text is read, for example rhetorical devices, are generated from the microscopic codes in the text.

Barthes emphasised that the breaking apart of the text was purposeful, deliberate. The intention was not to recompose the text according to a larger model, but to analyse how it produces meanings. 'I have commented' wrote Barthes in the introduction 'not in order to make intelligible, but to know what the intelligible is' (*S/Z* introduction to French edition). And finally, Barthes purposefully makes use of digression ('a form ill-accommodated by the discourse of knowledge' p13) in his commentary as a way of avoiding closure and finality in the reading. The analysis is, in a real sense, and purposefully, a re-writing of the original text.

The result is not an effort to establish the truth of the text but the way it is open to multiple interpretations. The product is not a critique of the text but 'the semantic substance' which different kinds of criticism (in Barthes' example 'psychological, psychoanalytic, thematic, historical, structural' p14). Barthes proposes not to 'respect' the tutor text but break it, interrupt it. Not to deny its quality but its naturalness (Barthes 1970 p15)

Among other things, *S/Z* is Barthes' most systematic account of codes, a term which occurs frequently in his work, regularly acquiring new meanings, beginning with the codification of myth in language in the *Mythologies* of the 1950s, through analyses of fashion (the vestimentary code), love, and photography. In *S/Z* code is the organising principle; it 'is a perspective of quotations; a mirage of structures' (Barthes 1970a p20), 'it is one of the forces that can take over the text'. Codes, like language, are constitutive as well as well as a method of transmission. They are like DNA code - a condensed formulation by which the visible structures are generated. And like DNA code, as people are increasingly recognising, the same code can give rise to different phenotypes because of the epigenetic environment in which the DNA is expressed.

The importance of *S/Z* was immediately recognised. However, despite the detailed step-by-step formulation it contains, and Barthes' own view that the codes could be applied outside of literature,³⁰ it has not been applied to many literary works (never according to John Sturrock (Sturrock 1998:33) although (Whitehead 1992) found a

³⁰ 'This theme of the relationship between metaphor and scientific discourse - I've always been alert to it ...the normative distinction between science and writing turns on the rejection/acceptance of images; now as it happens the exact sciences do resort to metaphor and what's more tend to come up with very good ones (Barthes *Preparation of the novel*. Columbia University Press 2011, p113)

single example in a reading of DH Lawrence's *St Mawr*) and has not been applied at all outside literary studies.

Summary - text, code, fragment

The transition whose most visible output is S/Z, took place over several years, and can be summarised as a transition from a structural approach to the following:

- Narrative is everywhere
- Attempting to assemble a unitary model of narrative misses one of its main characteristics, which is polysemy
- The most fruitful model of narrative is as text, in the sense described in (Barthes 1971c)
- Instead of a unitary model a work may be broken apart to locate functional components
- The functional components (Barthes calls them *lexias*) are fragments of text whose functions are shown by the narrative codes they contain
- Text becomes narrative by passing through these codes. The sequencing and ordering of the functional components is determined by the reader not the author.

3 The potential for applying S/Z to scientific texts

Scientific papers

According to the International Association of Scientific, Technical and Medical Publishers ‘there were about 33,100 active scholarly peer-reviewed English-language journals in 2018, collectively publishing some 3 million articles a year.’, with a total cost of production, including the research itself, of £175bn (Johnson 2018).

The scientific papers in these journals are dense, meticulous, and modest; they aim to be objective, to avoid ambiguity, and concern themselves with empirical truth or at least of accuracy. But objectivity is not their only goal. As the authors of the *Manual of Scientific Style* write, and as Shapin and Shaffer identified in the workings of seventeenth century science, ‘there must also be a profound sense of reality—a connection to the genuine human thought processes that gave rise to theories; to the details and vicissitudes of the experiments that support one contention or another; to the real life circumstances of science and to the very human concerns that color what on the surface seem to be highly theoretical concerns, even when dealing with the hardware and measurements of the laboratory (Rabinowitz and Vogel 2009). As this excerpt from the style guide shows, the characteristic style of stylelessness in scientific writing is ambitious and not easily achieved.

In addition, before publication, scientific papers are subject to peer-review (discussed in (Tennant 2020)) in which fellow scientists undertake a kind of literary criticism (peer review is of the text, and is unlikely to review the actual data, laboratory notebooks and so on) - is the paper written coherently, are its claims clear, are they plausible, are they likely to be of interest to other people in the field, and so on? And after publication, papers will be subject to scrutiny and commentary. So whatever aspiration scientific writing has to be pure communication, it is always subject to some of the process of literary production; they are always subject to readings other than the one intended by the authors. They are, to use Barthes phrase, moderately plural (Barthes 1970b p6).

Applying S/Z to a scientific paper

Some specific issues arise when considering applying the techniques of S/Z:

Which text to choose?

Barthes claimed that the tutor text for *S/Z*, the short story by Balzac, came to him without any great deliberation. There is no reason to doubt this, but the claim is part of a strategy for asserting that his method of analysis would apply to any literary text. Similarly, we would like to say that any scientific text might be chosen for analysis. But in practice there are choices to be made. Firstly, what type of text? I would like to

choose a scientific paper rather than a textbook because this seems most amenable to systematic analysis. Second, which science? It has to be a science that is accessible to my reading. And a historical consideration - is it easier, or better, to use a current text, or one from the recent past, or even one from earlier centuries? And finally a question about status. Is it more productive to apply the analysis to a paper that has been accepted into the scientific canon, or are retracted or discredited papers equally suitable? Perhaps even fabricated research, truly a kind of science fiction, which accounts for around 1 in 10 papers depending on definitions and reporting methods (Fanelli 2018).

I do not know the answer to most of these questions, but there is one principle that must apply. The analysis is not about the truth of its contents; nor to investigate the meaning of a scientific paper. The analysis is of how a paper establishes a credible relationship with truth and how it produces meaning - how it connects to reality, how it sets out its testable logic.

Taking all these points, the criteria for choice of paper are that it is accessible to my reading; that it has been published in a reputable peer-reviewed scientific journal; and that it should be freely available to read, i.e. that it is open access.

Do Barthes' narrative codes apply?

Barthes said in an interview that he considered the idea of a sixth code relating to the author, but rejected it. And in S/Z he made a point of emphasising that the five codes appeared within the title and first sentence of the analysis, and that without straining a point the text of *Sarrasine* falls under these codes. It seems important therefore, in terms of the purpose of my analysis, to see if the five narrative codes might cover a scientific paper too.

A preliminary conclusion is that they might:

- A scientific paper usually presents as a mystery, a question. In formal terms it sets out a hypothesis which it will eventually answer. The **hermeneutic** code runs through a scientific paper as its organising principle.
- As with any narrative a scientific paper will contain many signifiers. But a feature of scientific paper is that it will contain as little ambiguity or connotation as possible. The style of writing is purposefully, dry, direct, mono-semantic. Yet the **semantic** code is still present in a scientific paper, because unless one imagines a language which directly represents signifieds, and so is free from equivocal and synonyms, as John Wilkins did in the early days of the Royal Society (Maat 2004 p 152), language will always contain the capacity to signify more than its signifieds. If science *is* a type of literature, it is a literature of

declarative sentences, and so participates in the myth of language as nature. As Barthes wrote, 'doesn't a sentence, whatever meaning it releases, subsequent to its utterance, it would seem, appear to be telling us something simple, literal, primitive: something true, in relation to which all the rest ... is literature? That is why, if we want to go along with the classic text, we must keep denotation, the old deity, watchful, cunning, theatrical, foreordained to *represent* the collective innocence of language' (Barthes 1970b p9).

- Does a scientific paper include a **symbolic** network of the sort Barthes detected in *Sarrasine*? The network constitutes rhetoric, so the question might be put - does science contain rhetoric? In the sense of containing verbal deceit, no. In the sense of being organised to be persuasive, yes as Jeanne Fahnestock demonstrates in *Rhetorical Figures in Science* (Fahnestock 1999) . To take one example of rhetoric that she highlights, *ploche* - the precise repetition of a term across several sentences in order to stabilize the terms of an argument. The repetitive use of the term QALY (Quality Adjusted Life Year) in health research is an outstanding example of rhetorical ploche, in which a complex and contestable concept becomes stabilized through repetition, immune from analysis, amenable because real to measurement and statistical analysis.
- It is clear that **proairetic** codes form a major part of a scientific text, because texts describe the sequence of actions taken to perform the experiment, to collect the and then analyse the data. The basic design of an experiment, as taught in schools - Introduction, methods, results, and discussion - is found almost everywhere in scientific papers. It may be, as Peter Medawar suggested (Medawar 1963), largely a rational reconstruction of the actual events of a scientific experiment. And certainly scientists are finding it difficult to replicate experiments from given accounts. But the basic design of a scientific paper provides a telling example of proairesis - the arcing logic informing human actions.
- In Barthes' analysis science formed part of the **cultural** code, part of the background of knowledge to which the narrative could draw upon. But if a scientific paper becomes the object of analysis then the cultural codes informing it are slightly different. The network of references play a critical role in establishing the wider epistemological context for the scientific paper, and have an advantage in being explicit. But like a story, a scientific text will draw on the culture in which it exists, and we can provisionally say that both types of text contain cultural codes to roughly the same extent.

To summarise: Barthes' five narrative codes apply to scientific texts. The symbolic , proairetic, and cultural codes are present in the same way and to the same extent as in a

work of fiction. The hermeneutic code is present, probably to a greater degree than in most non-scientific texts. The semantic code is present but probably in a reduced quantity.

Are 5 codes sufficient?

‘The first three lexias - the title and the first sentence of the story - have already provided us with the five major codes under which all the textual signifiers can be grouped: without straining a point there will be no other codes throughout the story but these five’ (Barthes 1970b p 18-19) There is no particular numerology about the number of codes. Barthes said in an interview (reference lost) that he planned a sixth code about the author, but dropped it.

A working hypothesis can be that the five narrative codes can be used to dismember a scientific paper. But are there elements that aren’t covered by the narrative codes? There are at least three types of object in a scientific paper which on first encounter do not appear in literary texts and so may not be covered by the five codes: tables; illustrations; and mathematics. Mathematics, the most troubling because it is the least present in fiction, and because it is seen as a guarantee of facticity, was considered in Section 1.

Tables are the least problematic because they are the closest to being text. They are also clearly rhetorical - practical strategies for organising, summarising and displaying information in a way that helps the argument. The development of the tabulated form of presentation in the British Medical Journal in the nineteenth century was clearly a rhetorical strategy to bind together the early British medical profession through collective knowledge making (Toth 1989). Provisionally, it seems reasonable to imagine that where tables appear they can be considered in whole or part as lexias principally assigned to symbolic narrative codes.

Illustrations appear regularly in scientific texts. Historians and philosophers of science took little interest in illustration at one time, when the meaning of science was entirely conveyed in words. That is no longer the case. At least since Shapin and Shaffers’s *Leviathan and the Air Pump* (Shapin and Shaffer 1985), which argued that text itself might be considered a visual device, the importance of images and imagery in analysis has been recognised. The art historian Martin Kemp discussed the role of images in anatomical texts describing them as ‘the rhetoric of the real’ (Kemp 2010). Katherine Acheson, in her study of visual rhetoric in early modern English argues that ‘visual modes of communication can be transferred, at the conceptual level, to works in other media’ (Acheson 2013 p10). Jonathan Buehl argues that rhetoric ‘can provide the analytical machinery needed to grapple with the multimodal means used to create scientific arguments (Buehl 2016 p8). A similar approach is followed here.

4 A text analysed

The first text chosen for analysis is *Broken sleep predicts hardened blood vessels* (Vallat et al 2020) chosen from the peer reviewed open access scientific journal PLOS Biology. The article was chosen because of the journal's reputation among scientists; the immediately evident quality and completeness of its methods; and because of its accessibility to my reading.

The article is the report of a population based study of the association between sleep disturbance and heart disease, with the hypothesis that any association between them is mediated by the effect of sleep disturbance on white blood cells. The complete text is available from the URL below. The analysis omits some of the supplementary material: <https://journals.plos.org/plosbiology/article?id=10.1371/journal.pbio.3000726>

(1) *Broken sleep predicts hardened blood vessels*

★ The title provides a complete account for those unable to read the whole of the text. A question has been asked and answered (HER. Enigma 1: question: a question has been answered). ★ ★ Shorn of elaboration, this compact fragment of text is also a declaration that the text is connected to positivism, to objectivity (SEM: plain speaking).

(2) *Abstract*

Why does poor-quality sleep lead to atherosclerosis? In a diverse sample of over 1,600 individuals, we describe a pathway wherein sleep fragmentation raises inflammatory-related white blood cell counts (neutrophils and monocytes), thereby increasing atherosclerosis severity, even when other common risk factors have been accounted for. Improving sleep quality may thus represent one preventive strategy for lowering inflammatory status and thus atherosclerosis risk, reinforcing public health policies focused on sleep health.

★ The abstract, which reprises the paper, poses the question which was answered in (1) (HER. Enigma 1 : question: a question has been answered). ★ ★ As the abstract suggests, and will become increasingly clear, the question and its answer in the body of the paper are different to the one in fragment (1) (SYM Asyndeton) ★★ ★ The abstract also suggests the means by which the findings of the paper might reinforce public policy. (SYM: homiletics).

I. Repetition

The passage of time is almost absent from this paper; the main form of narration is repetition: The title contains the story; the abstract summarises the story; and the main

body of the paper sets out the story in full, though even within the main body of the text the story is repeated as summary in fragments 19 and 21.

One feature of the text that close reading can show is the modifications to the story that take place. In this case the hypothetical-deductive element to the story, its enigma, is modified through discussion as the data emerges.

(3)

<p>Citation: Vallat R, Shah VD, Redline S, Attia P, Walker MP (2020) Broken sleep predicts hardened blood vessels. PLoS Biol 18(6): e3000726. https://doi.org/10.1371/journal.pbio.3000726</p>
<p>Academic Editor: Paul Shaw, Washington University in St. Louis, UNITED STATES</p>
<p>Received: December 10, 2019; Accepted: April 27, 2020; Published: June 4, 2020</p>
<p>Copyright: © 2020 Vallat et al. This is an open access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.</p>
<p>Data Availability: The MESA dataset can be obtained, with the appropriate permissions, through the BioLINCC repository at: https://biolincc.nhlbi.nih.gov/studies/mesa/. In addition to the public access repository, interested investigators may also access the data through the MESA Coordinating Center at the University of Washington. Use of the data via this mechanism is overseen by standard MESA policies and procedures, which assure that participant consents are honored. Additional information can be found at: https://www.mesa-nhlbi.org/. Data from the MESA ancillary sleep study are available from the National Sleep Research Resource website (https://doi.org/10.25822/n7hq-c406).</p>
<p>Funding: This was not an industry supported study. MESA is supported by NHLBI funded contracts HHSN268201500003I, N01-HC-95159, N01-HC-95160, N01-HC-95161, N01-HC-95162, N01-HC-95163, N01-HC-95164, N01-HC-95165, N01-HC-95166, N01-HC-95167, N01-HC-95168, and N01-HC-95169 from the National Heart, Lung, and Blood Institute, and by cooperative agreements UL1-TR-000040, UL1-TR-001079, and UL1-TR-001420 funded by NCATS. MESA Sleep was supported by NHLBI R01 HL098433. SR was partly supported by NIH NHLBI R35HL135818. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.</p>
<p>Competing interests: The authors have declared that no competing interests exist.</p>
<p>Abbreviations: AHI, apnea-hypopnea index; ApoB, apolipoprotein B; BMI, body mass index; CAC, Coronary Artery Calcification; CPAP, continuous positive airway pressure; DBP, diastolic blood pressure; HRV, heart rate variability; MESA, Multi-Ethnic Study of Atherosclerosis; NREM, non-rapid eye movement; PSG, polysomnography; SBP, systolic blood pressure; WASO, wake after sleep onset</p>

★ The sidebar (in this case a textbox) is a feature of modern publishing, a way to add detail without overwhelming the main body of the work. The individual facts presented in this sidebar have many purposes, but for this reading the sidebar forms a unified warranty that it conforms to the standards of modern scientific practice. (REF: the practice of science: transparency). ★★ Here, in compact form, and in many places

throughout the text, the practice of referring to external sources grounds the text in reality (SEM: realism).

(4) **Introduction** ★ This heading, along with the others in the paper, indicate that the argument in the narrative is structured according to the rhetorical conventions of scientific writing (SYM: scientific style).

II Density

As Suppe argues, every part of the text has an epistemic function (Suppe 1998). Scientific texts are very compact, which is itself a connotation that the language means little in comparison to the facts. But the text is also a protective shell - the reading eye glides from fact to fact until it reaches the conclusion of the story.

(5) *Sleep disruption is associated with atherosclerosis.* ★ An opening statement sets the scene in which the research will take place. (REF: knowledge about sleep) ★★ The supporting references, which lead to a metaanalysis [1] and an animal study [2] are not as definitive as the assertion; the purpose of the reference is twofold: to connect this study to the community of scientists and to ground the text in reality (SEM: scientific realism).

III Poetry

From an analytic point of view technical vocabulary joins the text, through reference to the culture of science; or connotation to scientific realism. It can also, as here, join another literature, that of insomnia and death. In *Aubade*, Philip Larkin wrote:

*Waking at four to soundless dark, I stare.
In time the curtain-edges will grow light.
Till then I see what's really always there:
Unresting death, a whole day nearer now,* (Larkin 1977)

(6) *Why is this? One potential pathway through which fragmented sleep causally triggers cardiovascular disease is via the up-regulation of inflammatory-associated white blood cells, which incite atherosclerosis [1,2]. However, the proposition that sleep fragmentation in humans is associated with atherosclerosis through the mediating influence of increased neutrophil and monocyte counts remains unexplored [3–5]. Moreover, that such a pathway is evident even when accounting for common contributing factors leading to atherosclerosis—such as age, sex, ethnicity, body mass index (BMI), smoking status, blood pressure, use of antihypertensive medication, sleep apnea, and insomnia—is similarly unknown. Here, we address these unresolved questions.*

★ There are uncertainties that the paper will resolve (HER: Enigma 1: what is the connection between fragmented sleep and atherosclerosis in humans?) ★★ The text is also about a journey - a pathway - from insomnia to death. But the characters who will make this journey are somewhat abstract.

IV Action

Does anything happen in a scientific story? As Morgan and Wise suggest, time in a scientific narrative often unfolds logically rather than chronologically (Morgan and Wise 2017 p9), and little falls under the code of action. There is the movement from an enigma set to an enigma resolved, and within this narrative arc various things happen. In this particular story, some of the actions are described, but most is only hinted at, patients are recruited, data is collected, data is analysed, and so on. Most of the action in a scientific paper takes place off stage, as if it didn't matter.

(7) Specifically, we test the hypothesis that the impact of fragmented sleep on atherosclerotic pathology is governed, in part, through the novel mediating influence of increased neutrophil and monocyte levels and, furthermore, that this sleep-related disease pathway is robust when multiple alternate cofactors (disease mechanisms) are being controlled for.

★ (REF: the practice of science: hypothesis testing)

(8) To do so, we examined the association between sleep fragmentation (measured using 2 independent sources of objective data: polysomnography [PSG] and multiple nights of wrist-based actigraphy), white blood cell count, and in vivo measures of subclinical atherosclerosis in a diverse sample of the population (n = 3,305).

★ The first stages of the actions taken which will resolve the enigma are described (PRO: collection of data) ★★ This is the first fragment to contain mathematical notation, all of which are part of a network which will form the connection between the text and reality. (SYM: scientific realism: ecphrasis).

(9) The characteristics of the cohort, stratified by atherosclerosis severity category, are shown in [Table 1](#), and the sleep parameters of the cohort are presented in [SI Table](#).

★ (SEM: realism). ★★ (SYM: scientific realism: ecphrasis)

V Realism

The circuit which ties together realism, objectivity, and quantification exists in the text. As Agazzi writes 'If the 'object' of a science is, by definition, something which must (in principle) be an object for all subjects, it cannot be but an intellectually constituted structure' (Agazzi 2014 p99).

Rom Harre argues that revealing the rhetorical character of science serves to support realism rather than undermine it (Harre 1996). Harre is interested in what he calls, after

Wittgenstein, states of affairs; and in the rhetorical transformation from data to facts supported by scientific grammar. What Harre calls grammar we might today call a model; the purpose of grammar, states of affairs, and models is to generate and present to the reader pictures of reality. In the case of certain nineteenth century novels, Barthes characterised what he called the reality effect as a textual effect arising from the accumulation of seemingly unimportant words and phrases in the text (Barthes 1968a). Similarly here, we describe a scientific reality effect. But instead of it being located in unimportant detail, the scientific reality effect is constructed at many points in the text, as a circuit involving objectivity and quantification, constituted and supported by three of the narrative codes, the semantic, the symbolic, and the referential. According to the *Manual of Scientific Style* there must be ‘a profound sense of reality’ (Rabinowitz and Vogel 2009: vii) in a scientific text. The phrasing is interesting because it places a burden on the text to deliver a sense of reality, and put this way the matter is really quite close to Barthes’ conception of Reality Effects in nineteenth-century fiction.

At this point in the paper the tables of quantitative data (Table 1 and S1 Table) connect to the real world on the basis of a fundamental model used in human research, that of population modelling (Desrosieres 1993) (Porter 1995). The act of reading - or seeing - the tables reconstitutes the text, and generates a reality effect by passing it through narrative codes.³¹ The reader becomes a virtual witness to the reality of the experiment (Shapin and Shaffer 1985). What figure of rhetoric can the elements of scientific realism such as a table of data be gathered under? I suggest *ecphrasis*, ‘a descriptive speech that brings the subject shown before the eyes with visual vividness’ (Squire 2015).

There is a broader question, more or less explicit in any discussion of language, of where reality is located. Fictional texts have an ambiguous relation to reality. But so too, I argue, does science. For the purposes of what I am interested in, one might say science tries to bring reality into its texts by a series of literary techniques which can be analysed as mechanisms and maneuvers Barthes attended to from his perspective in Reality Effects. As Jonathan Culler notes ‘Details that do not contribute to plot, suspense, character, atmosphere, or symbolic meaning, nevertheless have a signifying function, he concludes, by their very absence of meaning they signify, ‘we are the real’.’ (Culler ...p128) A scientific text offers a plenitude of detail whose function is, on top of narration, to lay claim to reality. Science is of course real, but it is worth noting the difficulty scientists are finding in trying to reproduce the results of experiments from the descriptions given in scientific papers. This failure does not point to a fraud in the accounts of experiments, but to the complexity of the relationship between texts and reality.

³¹ ‘The five codes create a kind of network, a topos, through which the entire text passes (or rather, in passing, becomes text)’ (Barthes 1970b p20).

(10) *The unadjusted bivariate correlations described in the following paragraphs are shown in [S1 Fig](#).*

★ The first step in the mathematical analysis is the analysis of variation - the correlation between items of data collected from the study subjects. Later it will become clear that the analysis takes place in two stages. (PRO: analysis of data)

(11) **Results** ★ The paper moves to a description and analysis of data (SYM: organisation of scientific papers: rhetoric)

(12) **Actigraphy** ★ The recording of biometric data via a non-invasive device (REF: technical language) ★★ (SEM: science)

(13) *Focusing first on direct associations (prior to testing the mediation hypothesis and the inclusion of cofactors), actigraphy-measured sleep fragmentation positively and significantly predicted Coronary Artery Calcification (CAC) score ($r = 0.18$, $p < 0.001$; Fig 1A and S1 Fig). Second, this same objective measure of sleep fragmentation positively predicted higher neutrophil count ($r = 0.08$, $p < 0.01$) and was not significantly correlated with monocyte count ($r = 0.04$, $p = 0.17$). Third, both neutrophil and monocyte counts were positively associated with the CAC score ($r = 0.12$, $p < 0.001$ and $r = 0.14$, $p < 0.001$, respectively). ★ The initial analysis mentioned in (10) is presented. It shows that both white cell count (neutrophils but not monocytes) and sleep fragmentation are correlated. (PRO: analysis of data) ★★ The measurements are presented quantitatively, r being a measure of the strength of correlation between variables, and p which shows the probability that this value may occur by chance. (SYM: reality effect, euphemism). ★★★ r values vary between 0 and ± 1 . An r value of less than 0.2 is regarded as weak or poor (Acoglu 2018 Table 1) whatever the p value. To say the variables were positively associated is true, but euphemistic (SYM: rhetoric: euphemism).*

(14) *Having established each individual direct association, we next tested the central hypothesis that the relationship between sleep fragmentation and atherosclerosis pathology (CAC score) was not direct but, instead, statistically influenced through the indirect mediating impact of fragmented sleep on raised neutrophil count, which in turn predicted CAC score. Supporting this proposed pathway, the impact of sleep fragmentation on CAC scores was significantly mediated through the indirect pathway of raised levels of neutrophils ($n = 1110$, $\beta = 0.71$, 95% CI 0.18–1.65). Thus, sleep fragmentation was associated with atherosclerosis risk, yet this relationship was indirectly contributed to through the influence of fragmented sleep quality on increased neutrophil count. Consistent with the lack of a significant pairwise association between sleep fragmentation and monocytes, there was no indirect effect*

with monocyte count ($\beta = 0.35$, 95% CI -0.11 to 1.14), potentially suggesting a greater mediating role of neutrophil activity.

Numerous factors to date have been demonstrated to increase atherosclerotic risk, including age, sex, ethnicity, and BMI [6–8] as well as sleep-related features, including the presence of sleep apnea [9] and insomnia [10]. Importantly, the aforementioned mediation effect remained significant when controlling for the factors of age, sex, ethnicity, BMI, smoking status, blood pressure, and use of antihypertensive medication, as well as sleep apnea and insomnia diagnoses ($\beta = 0.44$, 95% CI 0.02 – 1.27 ; Fig 1A and SI Methods). The mediation also remained significant when excluding participants with a CAC score of zero ($n = 746$, $\beta = 1.05$, 95% CI 0.27 – 2.52) and in this more select cohort, again showed a significant mediation after controlling for all the aforementioned covariates ($\beta = 0.85$, 95% CI 0.11 – 2.36). Related, the mediation similarly remained significant when excluding 104 participants diagnosed with sleep apnea ($\beta = 0.64$, 95% CI 0.11 – 1.71 , controlled for all aforementioned covariates).

★ The analysis moves on to test what is described as the central hypothesis. The hypothesis has been modified to focus on neutrophils, and a strong mediation effect is found even when age, sex etc are taken into account (PRO: the development of the story. ★★ (REF: scientific method).

(15) Although in the same direction, the mediation effect was not statistically significant when adjusting for sleep apnea using the apnea-hypopnea index (AHI) estimated from the PSG night ($\beta = 0.35$, 95% CI -0.02 to 1.18). This indicates that sleep apnea cannot be excluded as a contributing factor in the mediation. However, post hoc analysis using AHI instead of sleep fragmentation as the exposure variable did demonstrate that there was no indirect effect of AHI on CAC via an increase in monocyte/neutrophil counts (neutrophil: $\beta = 0.12$, 95% CI -0.02 to 0.44 ; monocytes: $\beta = -0.05$, 95% CI -0.27 to 0.04). That is, sleep fragmentation, beyond AHI, appears to have a specific relationship with inflammatory-related increases in atherosclerosis. ★ (REF:10-15: biometric model)

VI Models

Models provide the best description of the way science is constructed, and it may be that literary theory provides a way to understand these models (Salis 2019). Are scientific models visible when the text is dissected?

In fact the text contains several models. Fragments (10)-(15) contain three models: two statistical models and a general biometric model which informs the statistical models.

The general model has been discernable in Western culture for two hundred years or more, it is everywhere and largely invisible, hence its effectiveness. Its components include population, variable, and distribution - a certain style of solving practical problems (Hacking 1981 p24). The model is noted as a reference code, numbered to indicate that it is spread across several fragments of text.

The first specific model describes correlation between two variables in a population, and includes a method to calculate a numeric value of the extent of the correlation and a way to calculate the extent that the extent of correlation is real.

The second - the mediation model - describes the way in which the correlation between two variables (disturbed sleep [the exposure variable] and atherosclerosis [the outcome variable]) might work via an intermediate variable (neutrophils). Mediation analysis seeks to understand how much of an exposure's effect on an outcome is diverted through a mediating variable.

These models are richly figured in narrative codes. The second model restates the main enigma of the paper in the most precise way: 'is atherosclerosis the result of neutrophil activity due to broken sleep? (HER code) The second model also provides a sequence of actions (PRO code).

VII Multiple readings

The p values - data produced by the models - are not about the degree of the correlation but about the certainty of the degree of the correlation - in this case the values merely indicate a high probability of a weak correlation. Paradoxically, because of their self image of objectivity, the results of statistical tests, and the tests themselves, can be points at which multiple and contested readings are possible (SEM code).

Polysomnography

Having quantified the association between atherosclerosis and home-based sleep, measured using wrist actigraphy, we further tested these same relationships using PSG-recorded sleep. Congruent with the actigraphy findings, the severity of PSG-measured fragmentation (arousals during non-rapid eye movement [NREM] sleep) directly and positively predicted CAC score severity ($r = 0.14$, $p < 0.001$). Once again, this association was indirect. Specifically, the impact of the PSG-measured arousal index in NREM fragmentation on CAC scores was mediated through raised levels of neutrophils ($n = 1046$, $\beta = 0.42$, 95% CI 0.13–0.94) and raised monocytes ($n = 1046$, $\beta = 0.32$, 95% CI 0.07–0.75). This effect was specific to NREM sleep, with no such significant associations with the arousal index measured during REM sleep ($r = 0.003$, $p = 0.92$).

The PSG-based mediation effect with neutrophils remained significant after controlling for age, sex, ethnicity, smoking status, and blood pressure ($\beta = 0.19$, 95% CI 0.01–0.61; Fig 1B). However, unlike the actigraphy-based measures, the effect did not remain

significant after adjusting for BMI, sleep apnea, insomnia, and use of antihypertensive medication. One interpretation is that 1 week of wrist-based actigraphy sleep measurement, relative to a single night of PSG sleep recording, is more capable of detecting the sleep-dependent link between neutrophils and atherosclerosis when considering relevant cofactors.

The indirect mediation effect with monocytes did remain significant after controlling for age and ethnicity ($\beta = 0.16$, 95% CI 0.01–0.49), but not after adjusting for sex, indicating that the atherosclerotic impact of sleep fragmentation on monocytes (but not neutrophils) is partially regulated by sex.

It is noteworthy that the sleep-atherosclerosis mediation measured using PSG was significant for both neutrophils and monocytes, while actigraphy-measured sleep only showed a significant mediation effect with neutrophils ($\beta = 0.36$, 95% CI –0.11 to 1.14). This may suggest greater sensitivity of PSG measures in quantifying this atherosclerosis disease pathway with multiple inflammatory-related factors while still underscoring the aforementioned PSG results concerning comorbidities.

★ The initial results, which measured sleep patterns using a wrist band, are checked using polysomnography, the more traditional technique used in sleep disorder investigation. (REF: scientific methods) . ★★ The use of a latinate term is standard among sleep scientists but emphasises the scientific nature of the story (SYM: scientific terminology). ★★★ The correlations using somnography do not concur with those of actigraphy. Reasons for this are discussed. The narrative journey, more logical than real is held up at this point (AET: delay).

(16) Subjective sleep

Having examined the association between atherosclerosis and objective measures of sleep, we tested for an equivalent relationship using subjective reports of sleep fragmentation. Self-reported sleep fragmentation was not associated with neutrophil count ($r = 0.009$, $p = 0.77$), monocyte count ($r = -0.056$, $p = 0.08$), or CAC score ($r = -0.042$, $p = 0.11$) and provided no indirect mediation effect of the association between white blood cells and atherosclerosis (neutrophils: $\beta = 0.73$, 95% CI –4.5 to 6.3, monocytes: $\beta = -4.3$, 95% CI –10.7 to 0.11). In addition, there was no direct or indirect effect of habitual daytime sleepiness (measured by the Epworth sleepiness scale [11]) on CAC score. These findings indicate that, unlike objective assessments, self-reported sleep quality and daytime sleepiness may not offer statistically sensitive measures in the predictive mediation pathway between sleep, inflammation, and atherosclerosis.

★ A subjective way of measuring broken sleep - self reported sleep quality - does not provide evidence to support the central or raw hypothesis in the study. It is suggested that subjective measures are not useful to statistical studies. (REF: scientific method)

(17) **Exploratory analyses**

Finally, we tested whether other objective sleep parameters, beyond sleep fragmentation, were similarly associated with atherosclerosis via an elevation in neutrophil and/or monocyte counts. Specifically, we looked at both actigraphy and PSG measures of sleep quantity and quality. Consistent with the aforementioned findings, PSG-defined wake after sleep onset (WASO) was indirectly associated with increased CAC through an increase in monocyte count ($\beta = 0.05$, 95% CI 0.01–0.13). Similarly, higher sleep efficiency (averaged across 7 days of actigraphy) negatively predicted a lower CAC score via a reduction in neutrophil count ($\beta = -1.12$, 95% CI -2.83 to -0.13). However, neither of these relationships remained significant after controlling for the earlier-mentioned cofactors. Thus, fragmented sleep, more than other sleep features, appears to be a particularly sensitive predictor of white blood cell-mediated atherosclerosis.

★ With the datasets available it was possible to explore possible correlations between other variables. Doing so suggests fragmented sleep is the only measure that remains significant after controlling for age, sex, etc. (REF: scientific method)

(18) **Discussion** ★ The discussion, as with most modern scientific papers, is divided into two parts. The first part is a summary of the findings including the implications for further research and for practice. The second part is a discussion of the limitations of the study, as if the authors were able to be both the positive authors and know the limitations. (SYM: scientific method)

(19) Together, these findings affirm a pathway in which the quality of human sleep, specifically the degree of fragmentation, raises inflammatory-related white blood cells, thereby conferring increased risk for atherosclerosis. This was true of sleep fragmentation assessed across a week or across a single night, which predicted increasingly higher CAC score through a mediating association with increased neutrophils.

★ Unlike a story, the narrative contains little action. Action is suggested here, but the actors are not people but ideas and things: broken sleep, white blood cells, atherosclerosis, possible components of an actor-network analysis (ACT: a journey).

(20) Our findings confirm recent seminal work in mice demonstrating that experimentally induced sleep fragmentation, associated with increases in blood levels of monocytes and neutrophils, results in larger atherosclerotic lesions [1,2]. Furthermore, these rodent data added mechanistic insight, with sleep fragmentation reducing hypocretin levels in the hypothalamus, signaling bone marrow-related increases in the production of monocytes and neutrophils. ★ (REF: existing knowledge)

VIII Animals and humans

Without much strain, the text weaves together knowledge derived from animal studies and human studies. This is a further model, or rule of construction, embedded in the text - that humans and animals can be similar enough to sit on the same page.

(21) Advancing this research, we establish a sleep fragmentation—white blood cell—atherosclerosis association in a population-based sample of human adults and demonstrate that these effects remained robust when accounting for multiple other common atherosclerosis risk factors present in humans: age, sex, ethnicity, BMI, smoking status, blood pressure, and use of antihypertensive medication, as well as sleep apnea and insomnia diagnoses. Finally, we show that this indirect pathway can be quantified with objective sleep metrics, either using 1 week of wristwatch actigraphy or a single night of PSG recording.

Importantly, however, we demonstrate that this same disease sensitivity is not observed when using self-reported subjective sleep fragmentation or other metrics of sleep quantity and/or quality. This may be pertinent for clinicians and researchers in determining which sleep measures should be focused on in this disease context.

Though our statistical models remained significant after adjusting for age (in addition to other cofactors), this does not challenge the well-established and independent links between (i) aging and increases in monocytes and neutrophils [12,13], (ii) increases in atherosclerosis risk [14], and (iii) decreases in sleep quantity and quality [15]. Rather, our findings simply indicate that the mediation relationship between sleep fragmentation, white blood cells, and atherosclerosis persist when chronological age is considered.

Decreasing sleep duration and fragmented sleep are independently associated with an increased risk of atherosclerosis [16,17]. However, the pathways through which the impact of sleep impairment operates have remained largely unknown. Building on rodent models [1], our findings suggest that one candidate pathway through which sleep fragmentation can raise atherosclerotic risk in humans may be through raised levels of inflammatory-associated neutrophil and monocyte counts. This proposal is consistent with findings that insufficient sleep (acute and prolonged) triggers low-grade inflammation [18], decreases and increases in discrete immune factors, and enhanced upstream signaling mechanisms of inflammation, including those regulated by monocytes [18]. Moreover, both monocytes and neutrophils have a recognized role in atherosclerosis, including the modulation of proatherogenic reactive oxygen species and neutrophil extracellular traps that encourage monocyte accumulation to the plaque site [19–24].

- ★ The ‘story’ is told at several points in the text, and is repeated here (SYM: precis)
- ★★ The findings are congruent with existing scientific knowledge about fragmented sleep and atherosclerosis (REF: existing knowledge, positivism)

(22) *What it is about fragmented human sleep that triggers inflammatory blood cell pathway continues to be defined. Beyond the inhibition of hypocretin production, sleep fragmentation results in hypercortisolemia [25,26]. The state of raised cortisol can prevent the inhibition of granulocyte macrophage colony-stimulating factor (GCSF) that otherwise limits neutrophil levels [27], and may therefore further increase neutrophil production [28,29].*

- ★ While the story has made a modest increase in the positive knowledge about the topic of [white blood cells-sleep-atherosclerosis] it also opens to further as yet unresolved questions. This fragment is both an enigma (HER: unresolved questions) and a sign, that the study conforms to the idea of science as an unending quest for knowledge (SEM: the image of science)

(23) *In the broader context of public health, these data suggest that improved sleep continuity (i.e., lowering of sleep fragmentation) may offer a novel preventive strategy for lowering inflammatory status and thus lowering relative atherosclerosis risk. More broadly, these findings could help inform public health guidelines that focus on societal sleep health, one benefit of which may be lowering atherosclerotic burden.*

- ★ The study may have implications for practice (SEM: the image of science)

(24) **Limitations**

- ★ Adding a section on the limitations of a study is a recent addition to the standard structure of scientific papers. It serves two purposes: firstly to preserve scientific decorum through modest speech; and secondly to anticipate, and so neutralise, criticism. There are two rhetorical figures, litotes and procatalepsis which appear at several points in fragment 25 (SYM:modest speech: litotes) (SYM: anticipating criticism:procatalepsis)

IX Masculine/feminine

The unrealistic aim of scientific writing is to be free from rhetoric. What this analysis suggests is that scientific writing is as densely loaded with rhetorical figures as any other form of writing. Such a suggestion of course will seem inappropriate or simply wrong. But rhetoric has not always been the unwelcome shadow of good writing. ‘In exploring the ways in which the observation reports of others are framed’ writes Daryn Lehoux... ‘we see that by the time of the early principate, much of the epistemological work being done in the Roman sciences is not happening under the exclusive eye of philosophy or of logic, but is happening under the auspices of a different discipline with a different set of tools for knowing, the discipline the Romans called rhetoric.’ (Lehoux 2012 p23).

The disappearance of rhetoric from positive knowledge can be seen in the fate of the figure of ecphrasis/ekphrasis. Most recently it is known, if at all, as a term to describe vivid description of a painting. However, as Courtney Roby observes, ‘Ekphrasis in antiquity was a broadly inclusive textual device, a fact largely ignored by modern critics who prefer to associate ekphrasis peculiarly with art objects’ (Roby 2016 p6). It originally referred to any speech that has the persuasive capacity of make-believe - to bring any object before the mind’s eye (Squire 2015). The most revealing definition of ecphrasis is that of the Oxford English Dictionary:

1715 Kersey, *Ecphrasis* (in Rhetoric) a plain declaration or interpretation of a thing.
1814 *Edin. Rev.* XXIV. 65 The same florid effeminacies of style · · in · · an ecphrasis of Libanius, are harmless. (OED 2nd edition 1989)

Originally intended as neither plain nor florid but vivid and effective (D’Angelo 1998) (Webb 2016), the demotion of ecphrasis to art theory (and femininity) encapsulates recent cultural beliefs about science and art, notably a view of scientific writing as having the masculine quality of freedom from rhetoric and narrative.

(25) A first limitation is that our analyses were constrained by the use of cross-sectional data, which precludes definitive assessment of directionality of associations. For example, it could be that cardiovascular disease (or associated treatments) may also drive sleep fragmentation in addition to, or rather than, the other way around. Although post hoc sensitivity analyses (S1 Results) indicated that incorporation of measures of cardiovascular disease did not substantively alter the significance of mediation effects in our cohort, this possibility remains. Prospective longitudinal controlled studies will be needed to directly address the issue of reverse causality.

★ The need for prospective longitudinal controlled studies is richly suggestive. Firstly, it suggests the way in which the present study can be extended in the future (SEM: the image of science), on the basis that the findings here do not fully achieve the goal of scientific causality (REF: scientific method: causality). It also anticipates criticism, forming a protective zone around the knowledge in this paper (SYM:modest speech: litotes) (SYM: anticipating criticism:procatalepsis).

(26) Second, it is important to note that while the indirect mediation pathways were statistically significant, the effect sizes of the pairwise associations were overall small. This suggests that raised inflammation (our a priori study focus) is likely one of a number of possible mechanisms through which insufficient sleep contributes to atherosclerosis. Other pathways include altered autonomic nervous system activity, increased oxidative stress, impaired glucose metabolism, and endothelial dysfunction [26,30–32]. While we were unable to explore each of these mechanisms, post hoc analyses revealed that the mediation pathway was also significant when using heart rate variability (HRV) during sleep as the exposure variable in the mediation

pathway—a well-established marker of the autonomic nervous system—instead of sleep fragmentation (see S1 Results). Sleep disruption is also associated with raised levels of apolipoprotein B (ApoB)—a strong predictor of cardiovascular disease [33] (though see [34]). Still, our findings indicate that one atherosclerotic mechanism in humans may involve the influence of fragmented sleep on raised inflammatory-associated neutrophil and monocyte count.

★ Noting that the degree of correlation in fragment 13 is rather low, the text suggests that the low level of correlation may be explained by other pathways. This modesty also situates itself in the stream of a positive accumulation of knowledge (SEM: image of science: positivism)

(27) The observed associations were not significant when adjusting for the AHI measured by PSG. Sleep apnea is well known to cause sleep fragmentation, and these results are consistent with sleep apnea as a factor contributing to sleep fragmentation. While our post hoc analyses suggest that AHI per se (independently of sleep fragmentation) is not statistically significantly associated with the inflammatory-related increases in atherosclerosis, it is likely that apnea-induced cortical and autonomic arousals play a mechanistic role in this indirect association between sleep, leukocytes, and atherosclerosis.

Our reported mediation effect was stronger for neutrophils, relative to monocytes, supporting a recent study demonstrating significant indirect associations between overnight heart rate, neutrophil count, and obstructive sleep apnea [32]. Nevertheless, the current study was not powered or designed to differentiate these individual cell contributions. We propose 3 speculative, non-mutually exclusive explanations for this stronger neutrophil relationship that may warrant future investigation. First, sleep disruption is linked to a larger relative increase in neutrophils compared with monocytes [35]. Neutrophils may therefore be the more sleep sensitive—and thus important—disease-related immune cell factor of this particular pathway. Second, neutrophils are more numerous than monocytes, making up 60% to 70% of the total white blood cell count. As such, a perturbation of white blood cells (e.g., by sleep disruption) may lead to their influence being more pronounced. Third, the measure of neutrophil count is encoded as a continuous variable, whereas monocyte count is encoded as a quasi-categorical variable (see S2 Fig), which may reduce monocyte sensitivity.

While the current study accounted for common comorbidities and cofactors (e.g., insomnia and sleep apnea diagnoses, obesity, sex, age, ethnicity, smoking status, blood pressure, hypertensive medication), it must be recognized that this does not exclude the contribution of all possible comorbidities. We also cannot rule out the chance that our findings may be influenced by selection bias. The original cohort consisted of individuals free of known cardiovascular disease. This may have led to an

underrepresentation of individuals with early-onset cardiovascular disease. Moreover, a small proportion (approximately 2%) of individuals were excluded from the Multi-Ethnic Study of Atherosclerosis (MESA) sleep exam due to regular continuous positive airway pressure (CPAP), oral appliance, or oxygen use, thus potentially reducing representation of those with clinically significant sleep apnea. However, the participation rate in the MESA sleep study subset was high (approximately 44%), and health profiles were generally similar between the participants who did enroll in the sleep study versus those who did not [7].

★ (SYM:modest speech: litotes) (SYM: anticipating criticism:procatalepsis)

(28) Taken together, our findings are consistent with the emerging idea of a pivotal role of neutrophils in atherogenesis [36] and establish that this association is in part mediated by sleep quality.

★ At its conclusion the story is summarised again (SYM:precis)

(28) References ★ (SYM: Scientific style)

(29) 1.McAlpine CS, Kiss MG, Rattik S, He S, Vassalli A, Valet C, et al. Sleep modulates haematopoiesis and protects against atherosclerosis. Nature. 2019;566: 383–387. Pmid:30760925

2.Tall AR, Jelic S. How broken sleep promotes cardiovascular disease. Nature. Nature Publishing Group; 2019. pp. 329–330. PMID:30783270

3.Solarz DE, Mullington JM, Meier-Ewert HK. Sleep, inflammation and cardiovascular disease. Front Biosci. 2012;4: 2490–2501. PMID:22652655

Etc

★ Very few literary works contain references, but all scientific papers do. Seemingly innocuous, references have many functions in a scientific paper. Ostensibly their function is to denote the object or concept to which a term in the main text refers (REF: scientific knowledge). ★★ In addition, by anchoring the text in the wider body of knowledge they help persuade the reader, through demonstration, of its value (SEM: value) ★★★ References, according to (Ginzburg 2012 p21) ‘as well as notes and the linguistic-typographical marks that accompany them, can be considered as equivalents of enargeia since they are procedures intended to communicate an effect of authenticity’. (SYM: enargeia) ★★★★★ The references as a whole perform a second rhetorical function, that of offering praise to the wider scientific community which this text intends to join (SYM: epideixis)

X The chain of reference

The references sometimes point towards technical manuals and databases but most often to other texts. Sometimes, the denoted text provides weak support. For example,

reference 26 is intended to support the idea of chronically raised cortisol levels following broken sleep. But the data in reference 26 are from 11 volunteers, over 2 nights, and found a borderline statistically significant increase in cortisol in 11 volunteers over 2 nights of experimentally induced broken sleep, an increase that remained within the normal range found in human subjects.

Avoiding criticism of the quality of referencing, one can say that if the idealisation of scientific reference is that of a signifier-sign-signified relation, the signified is more like another signifier, its text open to the same analysis here. So from the perspective of the sort of analysis we are undertaking here, references not only stabilise the primary text and offer praise, they also suggest a woven fabric, an unending text subject to the narrative codes suggested here.

5 Implications

Method

It has proven possible, without much difficulty, to undertake the sort of analysis reported here. In practical terms, once the text was chosen it was read over twice to establish the main lines of its narrative. It was then copied en-masse and read again, this time roughing out the lexias, numbering them and making notes in each to suggest the codes. Finally, the broken text was read several times, checking, modifying, and adding detail.

I am reasonably satisfied with my reading of the text. I know though that another person will break up the text differently and assign codes differently. This isn't a weakness in the method but fundamental to it. Barthes' work around the years 1966 - 1974, with its focus on pluralism and polysemy, provides a way to analyse scientific texts that is at once lucid, coherent, principled, and enabling.

The five codes

The five codes work as well for a scientific narrative as they do for a fictional narrative. A difference is seen in the distribution of the codes. Compared to a fictional text there are fewer enigmas in a scientific text; less action (and the action unfolds mainly in logical time); less connotation; more rhetoric (scientific texts are always trying to persuade); and a similar level of referencing, unless one takes each reference as separate in which case there is more anchoring of the scientific text in its immediate culture.

It sometimes seemed that a small fragment of text contained several codes, and that the codes were difficult to isolate from each other. 'Sometimes' Barthes writes. 'as the utterance proceeds. the rhetorical code is superimposed on the proairetic code''The rhetorical code, so powerful in the readerly text, produces offshoots at certain places in the sequence' (Barthes 1970b p 128-9)

Narrative and models

A close reading of a scientific text shows the traces of the narrative codes which form it. Can the same reading detect models, the other part of a modern theory of scientific texts? Especially if, as (Godfrey-Smith 2006) and (Salis 2019) argue, scientific models have something in common with literary constructions. So a question might be put, what is the relationship between narrative and models?

An immediate answer, based on Godfrey-Smith's characterisation, is that models and narrative are more or less co-terminus, more or less the same thing, both being instantiations of language. This answer isn't very satisfying because of the prevailing uncertainty about what models are, and because philosophy does not regard narrative as

a first class object. 'It should be noted,' wrote Krause and Bueno, 'that despite all the discussion about the concept of 'model' of a physical theory in the literature, the precise characterization of this concept remains elusive. (Krause and Bueno 2007). Stephen French quotes Bueno:

To consider them [the models] in this setting [model theory], a particular formalization of the language...is presupposed...if we do not have a formalized theory, how could we think of models in any reasonable sense, logical sense? Indeed what really are these entities, these models? (French 2020 p36)

The question of what semantic models are has troubled philosophy for some time. The answer is usually sketched in with reference to set theory and logic. A semantic scientific model 'as usually understood, is a structure, plus - crucially - an interpretation of a formal language in terms of that structure' (French 2020:36). But, as French goes on to describe (*ibid* 36-39), the differences between semantic and syntactic models of science, can be extremely arcane.

Secondly, most philosophers are suspicious of narrative, a term which easily suggests the lesser arts of storytelling and fiction. As Morgan observes 'Until now, philosophers of science have not given narrative much credence as having any epistemological functions and, if anything, have been deeply suspicious that it could have any such functions' (Morgan and Wise 2017).

The usual treatment of models is that they represent something

recognising that models, because they are intermediate objects, are an intermediate world which may rely on idealisations

But any interrogation of the implications of this raises many questions.

Might there be a simpler way of characterising models? A starting point is to observe the parallel between Barthes' approach to narratology and the semantic approach to scientific modelling. Barthes began *SZ* by comparing the intentions and performance of different sorts of models. One sort was constraining, reducing, as he put it, all the world's stories to a single model. The model he came to prefer, based on his fictive account of Japan and set out in his analysis of the novella *Sarrasine*. What emerged was a model of how narrative functions, but the model does not form a structure, it is a structuration, something that writing passes through to become text (Barthes 1970b

p20). And once the structuration process has occurred, when the science becomes text, it becomes closed, stable, nonreversible, and so becomes something that has a truth value, not necessarily true but something that is more or less scientifically plausible (Barthes 1970b p30). Similarly, what is called the semantic model can be regarded as a composite (Morgan and Morrison 2009), containing organised symbolic systems, which produce the effects seen in scientific papers - conjectures, refutations, data, objectivity, reality.

Mapping this onto French's definition, SZ is a formal modelling language. Its system of codes provides a way to describe the multiple models that contribute to the formation of the finished scientific text.

Is this a coherent and enabling theory?

Barthes' model (a more literary form of a cognitive frame [Camp 2020]) can account for narrative in a scientific text. And can make some claim to show how narrative, and the storied nature of models (Peschard 2007) work together. Answering Alan Gross's question, Barthes' work around the years 1966 - 1974 provides a framework that is at once lucid, coherent, principled, and enabling. Texts are expressive objects. They function according to rules of narrative which produce, well or badly, representation, objectivity, plurality, and indeterminacy. The fate of a text, scientific or nonscientific, is in its reading, its interpretation. And this changes over time. The truth value of the text

on disturbed sleep is relatively high in 2020. But in 2050 it may have lost this as science progresses.

The principal insights that made this paper possible came in the 1960s. Barthes wrote about the need to force science to confront its reality as writing in 1967 (Barthes 1967a) and Michel Foucault published a programmatic account of how to link scientific texts to wider practices in 1969 (Foucault 1969). If the most interesting way of talking about science today is in terms of semantic models, and if the best description of a semantic model is that of a hybrid/composite (Morgan and Morrison 2009), then a neglected literary model might have something to tell philosophy about the nature of science.

Bibliography

- Acheson, K. (2013) *Visual rhetoric and early modern english literature*. Ashgate.
- Adam, A. (ed) (2020) *Crime and the construction of forensic objectivity from 1850*. Palgrave.
- Agazzi, E. (2014) *Scientific objectivity and its contexts*. Springer.
- Agazzi, E. ed. (2017) *Varieties of scientific realism*. Springer.
- Ait-Touati, F. (2011) *Fictions of the cosmos - science and literature in the seventeenth century*. University of Chicago Press.
- Akoglu H. (2018). User's guide to correlation coefficients. *Turkish journal of emergency medicine* 18:91–93. <https://doi.org/10.1016/j.tjem.2018.08.001>
- Allen, G. (2003) *Roland Barthes*. Routledge.
- Amrine F (1989) *Literature and science as modes of expression*. Dordrecht: Kluwer.
- Andersen, W. (1984) *Between the library and the laboratory. The language of chemistry in eighteenth century France*. Johns Hopkins University Press.
- Arbib, M. and Hesse M. (1986) *The construction of reality*. Cambridge University Press.
- Armour-Garb, B. and Kroon, F. (2020) *Fictionalism in Philosophy*. Oxford University Press.
- Bachelard G. (2002) *The formation of the scientific mind*. Clinamen Press (originally published 1938)
- Badminton, N. (2016) *The afterlives of Roland Barthes*. Bloomsbury.
- Barthes, R. (1957) *Mythologies*. Editions du Seuil. "Pierres Vives" collection. First published in English as *Mythologies*. Jonathan Cape 1972.
- Barthes, R. (1964) Rhetorique de l'image. *Communications* 4:40-51. In Heath, S ed. & translated *Image, Music, Text*. New York: Hill and Wang, 1977. 32-51.
- Barthes, R. (1966) *Introduction to the structural analysis of narratives*. In Heath, S. *Image-music-text*. Fontana 1977.
- Barthes, R. (1964) Elements de semiologie. *Communications* 4:91-135. *Elements of semiology*. Farrar, Straus and Giroux, 1977.

- Barthes, R. (1967a) From science to literature. *Times Literary Supplement*. In *The rustle of language*. Basil Blackwell, 1986.
- Barthes, R. (1967b) *Système de la mode*. Seuil. *The Fashion system*. Hill and Wang, 1983.
- Barthes, R. (1968a) L'Effet de Réel *Communications* 11: 84–89 *The Reality Effect*. In *The Rustle of Language*. Blackwell 1986 pp 141-148.
- Barthes, R. (1968b) La mort de l'auteur. *Manteia V*:12-17. *The death of the author*. In Heath, S. *Image-music-text*. Fontana 1977.
- Barthes, R. (1970a) *L'empire des signes*. Skira. *Empire of signs*. Hill and Wang 1982.
- Barthes, R. (1970b) *S/Z - un essai* Seuil. *S/Z - an essay* Hill and Wang 1974.
- Barthes, R. (1970c) Interview conducted by Raymond Bellour, first published in *Les Lettres françaises*, 20 May 1970. *On S/Z and Empire of Signs*. In *The Grain of the Voice*. Hill and Wang. Seuil 1981.
- Barthes, R. (1970d) L'ancienne rhétorique: aide memoire. *Communications* 16. *The old rhetoric: an aide memoire*. In Barthes, R. *The Semiotic challenge*. University of California Press 1994.
- Barthes, R. (1971a) *Sade, Fourier, Loyola*. Seuil. Translation: *Sade, Fourier, Loyola*. Hill and Wang 1976.
- Barthes, R. (1971b) *La lutte avec ange*. In *Analyse structurale et exegese biblique*. Neuchatel. *The struggle with the angel*. In Heath, S. *Image-music-text*. Fontana 1977.
- Barthes, R. (1971c) De l'oeuvre au texte *Revue d'esthétique* 3:225-232. *From work to text*. *The rustle of language*. Blackwell 1986.
- Barthes, R. (1975) *Roland Barthes*. Seuil. *Roland Barthes* Hill and Wang 1977.
- Barthes, R. (1977) *Fragments d'un discours amoureux*. Seuil. *A lover's discourse - fragments*. Hill and Wang 1978.
- Barthes, R. (1980) *La chambre claire*. Seuil. *Camera Lucida*. Hill and Wang 1981.
- Barthes, R. (1986) *The rustle of language*. Blackwell.
- Barthes, R. (2009) *Journal de Deuil*. Seuil. *Mourning diary*. Hill and Wang 2010.
- Bauer, N. (2001) *Simone De Beauvoir, philosophy, and feminism*. Columbia University Press.

Beltagy, I. Lo, K., Kohan, A. (2019) SciBERT: a pre trained language model for scientific text. [arXiv:1903.10676v3](https://arxiv.org/abs/1903.10676v3)

Beer, G. (1983) *Darwin's plots*. Cambridge University Press.

Bloor, D. (1976) *Knowledge and social imagery*. University of Chicago Press.

Boodin, J. (1943). Fictions in Science and Philosophy. I. *The Journal of Philosophy*, 40(25), 673-682.

Brody, R. (2012) The uses of "Mythologies". *New Yorker* April 19th.

Buehl, J. (2016) *Assembling arguments. Multimodal rhetoric & scientific discourse*. University of South Carolina Press.

Bueno, O. and French, S. [2018] *Applying mathematics*. Oxford University Press.

Bueno, O, Darby, G, French, S., Rickles, D. eds. [2018] *Thinking about science, reflecting on art*. Routledge.

Caldwell, J. (2004) *Literature and medicine in nineteenth century Britain*. Cambridge University Press.

Camp, E [2020] *Imaginative frames for scientific inquiry. Metaphors, telling facts, and just-so stories*. In Levy, A. and Godfrey Smith, P. eds. *The scientific imagination. Philosophical and psychological perspectives*. Oxford University Press.

Carnap, R. (1942) *Introduction to Semantics*. Harvard University Press, Cambridge.

Carroll, N. (2001) *Beyond aesthetics: philosophical essays*. Cambridge University Press.

Cartwright, N. (1983) *How the laws of physics lie*. Oxford University Press.

Cartwright, N. (2010) *Models: parables v fables*. In R. Frigg, M.C. Hunter (eds) *Beyond mimesis and convention. Representation in art and science* Springer, Berlin, New York 2010 pp. 19–32

Cartwright, N. (2019) *Nature, the artful modeler: lectures on laws, science, how nature arranges the world and how we can arrange it better*. Open Court Publishing.

Ceccarelli, L. (2001) *Shaping science with rhetoric: the cases of Dobzhansky, Schrodinger, and Wilson*. University of Chicago Press.

Chakravartty, A. (2017) *Scientific Realism*, The Stanford Encyclopedia of Philosophy Edward Zalta (ed.), <https://plato.stanford.edu/archives/sum2017/entries/scientific-realism>

- Chico, T. (2018) *The experimental imagination - literary knowledge and science in the British enlightenment*. Stanford University Press.
- Clark, W. (1995) Narratology and the history of science. *Studies in History and Philosophy of Science* 26:1-7.
- Clark, B. (2017) *Wittgenstein, mathematics, and the world*. Palgrave Macmillan.
- Clifford, L. and Marcus, G.E. (1986) *Writing culture*. University of California Press.
- Collini, S. (2013) *Two cultures? The significance of CP Snow*. Cambridge University Press.
- Collins, H. M. (1985) *Changing order: replication and induction in scientific practice* University of Chicago Press.
- Cooter, R. (1984) *The cultural meaning of popular science: phrenology and the organization of consent in nineteenth-century Britain*. Cambridge University Press.
- Crossland, R (2018) *Modernist physics: waves, particles, and relativities in the writing of Virginia Woolf and DH Lawrence*. Oxford University Press.
- Culler, J. (1975) *Structuralist poetics*. Routledge & Kagan Paul.
- Culler, J. (2002) *Barthes: a very short introduction*. Oxford University Press.
- D'Angelo, F. (1998). The Rhetoric of ekphrasis. *JAC*, 18:439-447.
- Daston, L. and Galison, P. (2007) *Objectivity*. Zone Books.
- Davidson, D. (1977) Reference without reality. *Dialectica* 31: 247-258.
- Dennett, D. (1992) *The self as a centre of narrative gravity*. In Kessel, F. et al (eds) *Self and consciousness*. Lawrence Erlbaum.
- Desrosieres, A. (1998) *The politics of large numbers*. Harvard University Press.
- Drozdz, S. (2015) Quantifying origin and character of long-range correlations in narrative texts <https://arxiv.org/abs/1412.8319v2>
- Eagleton, T. (2008) *Literary theory*. Blackwell.
- Editors. (2013). The World Three of Karl Popper. *Open Science Repository Philosophy*, e70081900. doi:10.7392/openaccess.70081900
- Elgin, C. (2017) *True enough*. MIT Press.

- Engel, A. Lucido, K. & Cook, K. (2018) Rethinking Narrative: Leveraging storytelling for science learning *Childhood Education*, 94:4-12.
- Englehardt, N. (2018) *Modernism, fiction, and mathematics*. Edinburgh University Press.
- Fahnestock, J. (1999) *Rhetorical figures in science*. Oxford University Press.
- Fanelli, D. (2018) Is science really facing a reproducibility crisis, and do we need it to? *PNAS* 115:2628-2631.
- Fidler, F. and Wilcox, J. (2018) *Reproducibility of Scientific Results* In Zalta, E. (ed.) *The Stanford Encyclopedia of Philosophy (Winter 2018 Edition)* URL = <https://plato.stanford.edu/archives/win2018/entries/scientific-reproducibility/>.
- Field, H. (1980). *Science without numbers*. Princeton University Press.
- Fine, A. (1993) Fictionalism. *Midwest Studies in Philosophy* XVIII:1-18.
- Fleck, L. (1935) *Entstehung und Entwicklung einer wissenschaftlichen Tatsache*. Basel: Benno Schwabe und Co. *Genesis and Development of a Scientific Fact* (edited by T. J. Trenn and R. K. Merton, foreword by Thomas Kuhn). University of Chicago Press, 1979.
- Forman, P. (1971) ,Weimar culture, causality, and quantum theory, 1918–1927: adaptation by German physicists and mathematicians to a hostile intellectual environment. *Historical Studies in the Physical Sciences* 3: 1–115.
- Foucault, M. (1969) *L'Archéologie du savoir*. Éditions Gallimard. The archaeology of knowledge. New York: Pantheon Books, 1971.
- Fox Kellner E. (1992) *Secrets of life, secrets of death: essays on language, gender, and science*. Routledge.
- French, S. (2020) *There are no such things as theories*. Oxford University Press.
- Friend, S. (2007) Fictional characters. *Philosophy Compass* 2:141–156.
- Friend, S. (2019) *The fictional character of scientific models* in Godfrey-Smith, P. and Levy, A. (eds) *The Scientific Imagination* Oxford University Press.
- Frigg, R. (2010a) Models and fiction. *Synthese* 172: 251–268.
- Frigg, R. (2010b) *Fiction in science*. In John Woods (ed.) *Fictions and models - new essays*. Philosophia.
- Frigg, R and Hartmann, S. (2020) *Models in science* In *The Stanford Encyclopedia of Philosophy* (Spring 2020 Edition), Edward N. Zalta (ed.), URL = <https://plato.stanford.edu/archives/spr2020/entries/models-science/>.
- Frigg, R. and Hunter, MC. (eds) (2010) *Beyond mimesis and convention*. Springer.

- Galileo Galilei (1623) *The Assayer*. In S. Drake (1957) *Discoveries and Opinions of Galileo* Doubleday & Co.
- Galison, P. (2008) Ten problems in history and philosophy of science. *Isis* 99: 111-124.
- Garnett, M. ed. (2018) *Cambridge companion to narrative theory*. Cambridge University Press.
- Gelfert, A. (2016) *The ontology of models*. In Magnani, L. & Bertolotti, T. (eds.), *Springer Handbook of Model-Based Science*. Springer.
- Giere, R. (1999) *Using models to represent reality*. In Magnani, L. Nersessian, N and Thagard, P (eds) *Model-based reasoning in scientific discovery* New York, Plenum Publishers.
- Gillie, O. (1977). Did Sir Cyril Burt fake his research on heritability of intelligence? Part I. *The Phi Delta Kappan* 58:469-471.
- Gaonkar, D. (1993) The idea of rhetoric in the rhetoric of science. *Southern Communication Journal* 58:258-85.
- Gaukroger, S. (2020) *Civilization and the culture of science: science and the shaping of modernity, 1795-1935*. Oxford University Press.
- Ginzberg, C. (2012) *Threads and traces*. University of California Press.
- Golinkski J. (1995) *Making natural knowledge*. Chicago University Press.
- Godfrey-Smith, P. (2006) The strategy of model-based science *Biology and Philosophy* 21:725-740.
- Godman, N. (1976) *Ways of worldmaking*. Hackett.
- Gopnik M. (1972) *Linguistic structures in scientific texts*. The Hague: Mouton.
- Gossin, P. (2002) *Encyclopaedia of literature and science*. Greenwood Press.
- Gray, J. (2008) *Plato's ghost. The modernist transformation of mathematics*. Princeton University Press
- Green, B. S. (1983) *Knowing the poor - a case study in textual reality construction*. Routledge & Kegan Paul
- Green K. (2007) *Bertrand Russell, language, and linguistic theory*. London: Bloomsbury-Continuum.
- Greenhalgh T. (1999). Narrative based medicine: narrative based medicine in an evidence based world. *BMJ (Clinical research ed.)* 318:323–325.

- Gross, A. (1996) *The rhetoric of science*. Cambridge: Harvard University Press.
- Gross, A. (2006) *Starring the text. The place of rhetoric in science studies*. Southern Illinois University Press.
- Gross, A. and Keith W. eds. (1997) *Rhetorical hermeneutics*. State University of New York.
- Hacker, P. (2007) *Analytic philosophy: beyond the linguistic turn and back again*. In Beaney, M. ed. *The Analytic Turn*. Routledge.
- Hacking, I. (1975) *Why does language matter to philosophy?* Cambridge University Press.
- Hacking, I. (1981) How should we do the history of statistics? *I&C* 8:15-26.
- Hacking, I. (1983) *Representing and Intervening*. Cambridge University Press.
- Hacking, I (2015) *Let's not talk about objectivity*. In (Padovani 2015).
- Halliwell, S. (2013) *Diegesis – Mimesis*, Paragraph 8. In: Hühn, Peter et al. (eds.): *the living handbook of narratology*. Hamburg: Hamburg University. URL = <http://www.lhn.uni-hamburg.de/article/diegesis—mimesis>
- Hallin, F. (2000) *Metaphor and analogy in science*. Springer.
- Hamburger K. (1957) *The logic of literature*. 2nd ed Indiana University Press 1973. First published 1957 as *Logik der Dichtung*.
- Harding, S. (2015) *Objectivity and diversity*. University of Chicago.
- Harre, R. (1996) Rhetoric and realism. *Theoria: An International Journal for Theory, History and Foundations of Science* 11: 41-47.
- Harre, R. (1990) *Some Narrative Conventions of Scientific Discourse*. In Nash, C. ed. *Narrative in culture*. Routledge.
- Harre, R. (2004) *Models as metaphors* In Rothbart, D. ed. *Modeling: Gateway to the Unknown* A Work by Rom Harre. Elsevier.
- Harris, R. (2009). Alan Gross and the Rhetoric of Science. *Perspectives on Science* 17(3), 346-380.
- Hartmann, S. (2009). *Modeling in the philosophy of science*. In M. Frauchiger and W.K. Essler (Eds.), *Representation, evidence, and justification: themes from Suppes*. Frankfurt: Ontos Verlag.

- Hatavara, M. Hydén, L-C, Hyvärinen, M. (2013) *The travelling concepts of narrative*. John Benjamins Publishing.
- Herman, D. (1998). Narrative, science, and narrative science. *Narrative Inquiry*, 8(2), 379–390. doi:10.1075/ni.8.2.09her
- Hesse, M. (1963) *Models and analogies in science*. London: Sheed and Ward.
- Hesse, M. (1988) The cognitive claims of metaphor. *The Journal of Speculative Philosophy*. New Series, Vol. 2, No. 1 (1988), pp. 1-16
- Hirschkop, K. (2019) *Linguistic Turns 1890–1950: Writing on Language as Social Theory*. Oxford University Press.
- Hogben, L. (1957) *Statistical theory*. WW Norton.
- Honey, W. (1945) *Science and the creative arts*. Faber.
- Hopwood, N. (2015) *Haeckel's embryos*. University of Chicago Press.
- Horkheimer, M. & Adorno, T. (1944) *Dialectic of enlightenment*. New York, NY: Continuum. 1969.
- Howson, C. and Urbach, P. (2006) *Scientific reasoning: the Bayesian approach*. Open Court Publishing.
- Hylton, P. (2007) 'On Denoting' and the idea of a logically perfect language. In Beaney, M. ed. *The Analytic Turn*. Routledge.
- Hyman, W. (2017) 'Deductions from metaphors': figurative truth, poetical language, and early modern science. In Marchitello, H. and Tribble, E. (eds) *The Palgrave handbook of early modern literature and science*. Palgrave-Macmillan.
- Jameson, F. (1972) *The prison-house of language*. Princeton University Press.
- Jenkins, A. (2007) *Space and the 'march of mind': literature and the physical sciences in Britain, 1815-1850*. Oxford University Press.
- Jenkins, A. (2017) *Mathematics*. In Holmes, J. and Ruston S (eds) *The Routledge research companion to nineteenth century British literature and science*. Routledge.
- Johnson, R. (2018) *The STM report*. 5th edition International Association of Scientific, Technical and Medical Publishers
- Jordanova, L. (1992) *Sexual visions: images of gender in science and medicine between the Eighteenth and Twentieth centuries*. University of Wisconsin Press.
- Kahn, V. (2020) *The trouble with literature*. Oxford University Press.

Kamareddine F., Maarek M., Retel K., Wells J.B. (2007) *Narrative Structure of Mathematical Texts*. In: Kauers M., Kerber M., Miner R., Windsteiger W. (eds) *Towards Mechanized Mathematical Assistants*. MKM 2007, Calculemus 2007. Lecture Notes in Computer Science, vol 4573. Springer, Berlin, Heidelberg.

Kemp M. (2010). Style and non-style in anatomical illustration: from renaissance humanism to Henry Gray. *Journal of anatomy*, 216:192–208.

Krause, D. and Bueno, O. (2007) Scientific theories, models, and the semantic approach. *Principia* 11: 187—201.

Kiritchenko et al. (2010) ExaCT: automatic extraction of clinical trial characteristics from journal publications. *BMC Medical Informatics and Decision Making* 10:56
<http://www.biomedcentral.com/1472-6947/10/56>

Kroon, F and Voltolini, A. (2019) *Fiction*, The Stanford Encyclopedia of Philosophy (Winter 2019 Edition), Edward N. Zalta (ed.), <https://plato.stanford.edu/archives/win2019/entries/fiction>

Labinger, JA. and Collins, H. eds (2001) *The one culture*. Chicago University Press.

Larkin, P. (1977) *Aubade*. In *Collected poems*. Farrar, Strauss & Giroux 1988 p208.

Latour B and Woolgar S. (1979) *Laboratory Life: the social construction of scientific facts*. London: Sage Publications.

Lavers, A. (1982) *Roland Barthes: structuralism and after*. Methuen.

Lehoux, D. (2012) *What did the Romans know? An enquiry into science and worldmaking*. Chicago University Press.

Leitgeb, H, and Carus, A. (2020) *Rudolf Carnap*. In Edward N. Zalta (ed.) The Stanford Encyclopedia of Philosophy (Fall 2020 Edition), forthcoming URL =
<<https://plato.stanford.edu/archives/fall2020/entries/carnap/>>

Leng, M. (2010) *Mathematics and reality*. Oxford University Press.

Locke, D. (1992) *Science as writing*. New Haven: Yale University Press.

Lugton, RC. (1965) Ludwig Wittgenstein: the logic of language. *ETC: A Review of General Semantics*, vol. 22, no. 2, 1965, pp. 165–192.

Lutz, S. (2015) What was the syntax-semantics debate in the philosophy of science about? *Philosophy and Phenomenological Research*. doi: 10.1111/phpr.12221

Maat, J. (2004) *Philosophical languages in the seventeenth century: Dalgarno, Wilkins, Leibniz*. Springer.

- MacKenzie, D (1981) *Statistics in Britain 1865-1930: the social construction of scientific knowledge*. Edinburgh University.
- Markus, G. (1987) *Why is there no hermeneutics of natural sciences?* Science in Context 1: 5-51.
- McCloskey, D. (1998) *The rhetoric of economics*. 2nd edition Madison: University of Wisconsin.
- McCutcheon, M. (2018) *The medium is the monster. Canadian adaptations of Frankenstein and the discourse of technology*. AU Press.
- McQuillan, M. (2011). *Roland Barthes (or the profession of cultural criticism)*. Palgrave Macmillan.
- Medawar, P (1963). *Is the scientific paper a fraud?* Reprinted In Medawar, P. *The Strange Case of the Spotted Mice and Other Classic Essays on Science*. OUP 1996
- Morgan, M. (2017) Narrative ordering and explanation. *Studies in History and Philosophy of Science* 62:86-97.
- Morgan, M. and Morrison M. (2009) *Models as mediators. Perspectives on Natural and Social Science*. Cambridge: Cambridge University Press.
- Morgan, M. and Wise, N. (2017) Narrative science and narrative knowing. Introduction to a special issue on narrative science. *Studies in History and Philosophy of Science Part A*, 62:1-5.
- Mulkay M, Ashmore M, Pinch T (1987) Measuring the quality of life: a sociological invention concerning the application of economics to health care *Sociology* 21: 541-564.
- Nixon, K. (2020) *Kept from all contagion: germ theory, disease, and the dilemma of human contact in late nineteenth-century Literature*. New York: SUNY Press.
- Nottelmann, N. (2006) Otto Neurath on the structure of protocol sentences; a new approach to an interpretative puzzle. *J Gen Philos Sci* 37:165–186.
- Norris, C. (2001) *Literary theory, science, and philosophy of science*. In Knellwolf C, and Norris C (eds) *Cambridge History of Literary criticism Volume 9*. Cambridge University Press.
- Norris, S. P., Guilbert, S. M., Smith, M. L., Hakimelahi, S., & Phillips, L. M. (2005). A theoretical framework for narrative explanation in science. *Science Education* 89:535–563. doi:10.1002/sce.20063.
- Nussbaum, M. (1995) *Poetic justice: the literary imagination and public life*. Beacon Press.
- Ortolano, G. (2011) *The two cultures controversy*. Cambridge University Press.

- Oudshoorn, N. (1994) *Beyond the natural body*. London: Routledge.
- Padovani, F. et al eds. (2015) *Objectivity in science: new perspectives from science and technology studies*. Springer.
- Paul, H. (2011) *Hayden White*. Polity Press.
- Peschard, I. (2007) The values of a story *Principia* 11:151–69.
- Pickering, A. (1995) *The mangle of practice*. University of Chicago Press.
- Pino, C. A. (2019) The rhetorical mission: Barthes's seminars from 1964 to 1969. *Barthes Studies* 5:53-71.
- Poovey, M. (1998) *A history of the modern fact*. University of Chicago Press.
- Porter, T. (1995) *Trust in numbers*. Princeton University Press.
- Quine, W. (1951) Two dogmas of empiricism. *Philosophical Review* 60: 20-43.
- Quine, W. (2013) *Word and thing*. New edition MIT Press.
- Rabinowitz, H. and Vogel, S. (2009) *The manual of scientific style*. Academic Press.
- Raphael, R. (2017) *Reading Galileo: scribal technologies and the Two New Sciences*. Johns Hopkins University Press.
- Reed, J. (1989) On Narrative and Sociology. *Social Forces*, 68(1), 1-14.
- Reeves, C. (2005) *The language of science*. Routledge.
- Richards, T. (1993) *The imperial archive*. Verso.
- Rietveld, C et al (2013) [GWAS of 126,559 Individuals Identifies Genetic Variants Associated with Educational Attainment](https://doi.org/10.1126/science.1234567). *Science* 340:1467-1471.
- Roby, C. (2016) *Technical ekphrasis in Greek and Roman science and literature*. Cambridge University Press.
- Rouse J. (1990) The narrative reconstruction of science. *Inquiry* 33:179-96.
- Ryan, M-L. (2007) Towards a definition of narrative. In Herman, D. ed *The Cambridge companion to narrative*. Cambridge University Press.
- Salis, F. (2019) The New Fiction View of Models, *The British Journal for the Philosophy of Science*, axz015, <https://doi.org/10.1093/bjps/axz015>

- Samoyault, T. (2017) *Barthes: a biography*. Polity Press.
- Schleifer, R. (2000) *Modernism and time. The logic of abundance in literature, science, and culture 1880-1930*. Cambridge University Press.
- Scholes, R.C. , Phelen, K., Kellog, R. (2006) *The nature of narrative. 40th anniversary edition, revised and expanded*. Oxford University Press..
- Shapin, S (1979) The politics of observation: cerebral anatomy and social interests in the Edinburgh phrenology disputes. *Sociological Review* pp 139-178.
- Shapin, S. (1994) *A social history of truth. Civility and science in seventeenth-century England*. University of Chicago Press.
- Shapin S, and Shaffer S (1985) *Leviathan and the air pump*. Princeton University Press.
- Shteir, A.B. (1996) *Cultivating women, cultivating science*. Johns Hopkins Press.
- Shuttleworth S. (1996) *Charlotte Bronte and Victorian psychology*. Cambridge University Press.
- Sim, Ida et al. (2014) “The Ontology of Clinical Research (OCRe): an informatics foundation for the science of clinical research.” *Journal of biomedical informatics* 52: 78-91.
doi:10.1016/j.jbi.2013.11.002
- Sontag, S. (1982) *A Barthes reader*. Hill and Wang.
- Squire, M. (2015) *Ecphrasis: Visual and Verbal Interactions in Ancient Greek and Latin Literature*. Oxford textbooks online DOI: [10.1093/oxfordhb/9780199935390.013.58](https://doi.org/10.1093/oxfordhb/9780199935390.013.58)
- Stafford, A. [2018] Roland Barthes: A double grasp on reality. Times Literary Supplement.
<https://www.the-tls.co.uk/articles/roland-barthes-footnotes-to-plato/>
- Stenlund, S. (2002) *On the linguistic turn in philosophy*. In Gustaffson, M. and Hertzberg, L. *The practice of language*. Springer.
- Sterrett, S. (2002) Physical Models and Fundamental Laws: Using One Piece of the World to Tell about Another. *Mind & Society* 3:51-66.
- Strosberg, E. (2015) *Art & Science*. 2nd edition. New York: Abbeville Press.
- Sturrock, J. (1998) *The word from Paris: essays on modern French thinkers and writers*. Verso.
- Suarez, M. ed. (2009) *Fictions in science. Philosophical essays on modeling and idealization*. Routledge.

- Suarez, M. (2010) Scientific representation. *Philosophy Compass* 5/1:91-101.
- Suarez, M. (2016) *Representation in science*. In Humphreys, P. et al (eds) *Oxford handbook of philosophy of science*. Oxford University Press.
- Suppe, F. (1998) The structure of a scientific paper. *Philosophy of Science* 65:381-405.
- Suppes, P. (1993) *Models and methods in the philosophy of science. Selected essays*. Springer.
- Surkis, J. (2012). When was the linguistic turn? A genealogy. *The American Historical Review*, 117(3), 700-722. Retrieved June 10, 2020, from www.jstor.org/stable/23310547
- Tate, G. (2020) *Nineteenth-Century poetry and the physical sciences*. Palgrave.
- Tarski, A. (1944) The semantic conception of truth. *Philosophy and Phenomenological Research*;4:341-376.
- Tennant, J.P., Ross-Hellauer, T. (2020) The limitations to our understanding of peer review. *Res Integr Peer Rev* 5, . <https://doi.org/10.1186/s41073-020-00092-1>
- Toon, A. (2012) *Models as make-believe: imagination, fiction, and scientific representation*. Palgrave-Macmillan.
- Toth, B (1989) The development of clinical trials in Britain. PhD thesis. University of Bristol.
- Trifonas, P. (1997) *Barthes and the empire of signs*. Totem Books.
- Usman, J. and Cameron, A. (2006) Deceit and fraud in medical research. *International Journal of Surgery*. 4:122-126.
- van Fraassen, B. (1980) *The scientific image*. Oxford University Press.
- Van Fraassen, B. (2007) Representation and perspective in science. *Principia* 11: 97–116.
- Vallat, R, et al (2020) Broken sleep predicts hardened blood vessels. *PLoS Biol* 18(6): e3000726. <https://doi.org/10.1371/journal.pbio.3000726>
- Watkins, E and Stan, M (2014) *Kant's Philosophy of Science*, In Zalta, E. (ed) *The Stanford Encyclopedia of Philosophy* <https://plato.stanford.edu/archives/fall2014/entries/kant-science/>
- Webb, R. (2016) *Ekphrasis, imagination and persuasion in ancient rhetorical theory and practice*. Ashgate.
- Weisberg M. (2013) *Simulations and Similarity - using models to understand the world*. Oxford University Press.
- White, H. (1972) The structure of historical narrative. *Clio*, 1:5–20.

- White, H. (1984) The Question of narrative in contemporary historical theory. *History and Theory*. 23:1-33.
- Whitehead, F. (1992) Barthes Narratology. *Cambridge Quarterly*;XXI:41-64.
- Willis, M. (2015) *Literature and science*. Palgrave.
- Wittgenstein, L. (1971) *Prototractatus. An early version of Tractatus Logico-Philosophicus*. Routledge & Kegan Paul.
- Wittgenstein L (1993). Some remarks on logical form. In Klugge J and Nordman A (eds). *Ludwig Wittgenstein Philosophical occasions 1921-51*. Indiana: Hackett Publishing.
- Woods, J. (2018) *Truth in fiction: rethinking its logic*. Springer International. (Synthese Library vol 391)
- Woods, J. (2019) *On the follies of intercourse between models and fiction*. In Nepomuceno-Fernández, A. et al. (Eds.): *Model Based Reasoning* volume 49, SAPERE/Springer pp. 337–371
- Woods, J. and Rosales, A. (2010) *Virtuous Distortion: Abstraction and Idealization in Model-Based Science*. In L. Magnani et al. (Eds.): *Model-Based Reasoning in Science & Technology*, SCI 314, pp. 3–30. Springer Verlag.
- Woolgar, S. (1980) *Discovery: logic and sequence in a scientific text*. In Karin D. Knorr. Roger Krohn and Richard Whitley (eds.). *The Social Process of Scientific Investigation*. Sociology of the Sciences, Volume IV, Dordrecht: D Reidel 1980. P 239-268.
- Woolgar, S (1983) *Irony in the Social Study of Science* in K. D. Knorr-Cetina and M. Mulkay (eds.) *Science Observed: Perspectives on the Social Study of Science* London: Sage. pp. 239-66
- Wynn, J. (2012) *Evolution by the numbers: the origin of mathematical argument in biology*. Parlour Press.
- Zappen, J. (1989) Francis Bacon and the historiography of scientific rhetoric. *Rhetoric Review* 8:74-88.