

The Stories of Quantum Physics
Quantum Physics in Literature and Popular Science,
1900-present



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A thesis submitted for the degree of Doctor of Philosophy
Trinity Term 2017
93,209 words (approx.)

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Thesis Abstract

This thesis investigates quantum physics narratives for non-physicists, covering four interlocking modes of writing for adults and children, fictional and nonfictional, from 1900 to the present. It brings together three separate scholarly fields: literature and science, science fiction, and science communication. The thesis has revealed parallels between the approaches to quantum physics in these disparate narratives that have not been addressed before, shedding new light on the mutual influences between science and narrative form.

The thesis argues that similar narrative tropes have been employed in popular science writing and in fiction across all age groups, changing non-physicists' ideas of quantum physics. This understanding differs significantly from the professional understanding of quantum physics, as I establish by means of a series of case studies, including popular science books for adults by Alastair I.M. Rae, George Gamow and Robert Gilmore; popularizations for children by Lucy and Stephen Hawking, Russell Stannard, and Otto Fong; children's fiction by Philip Pullman and Madeleine L'Engle; and fiction for adults by Greg Egan, David Walton, Blake Crouch, and Iain Pears. An analysis of authors who wrote for various audiences or in multiple genres, such as Fred Hoyle, Stephen Hawking, and Ian Stewart, shows how the same concerns and conflicts surface in a wide range of stories.

Quantum physics is not yet fully understood; the Copenhagen, conscious collapse, many-worlds and other interpretations compete for both scientific and public acceptance. Influential physics communicators such as John Gribbin and Brian Cox have written popularizations in which they express a personal preference for one interpretation, arguing against others. Scientific conflict, which tends to be omitted from university teaching, is thus explicitly present in popularizations, making it clear to the reader that quantum physics is in a constant state of flux. I investigate the conflicts between Fred Hoyle and George Gamow, and Stephen Hawking and Leonard Susskind, to see how they undermine the alleged objectivity of science. The interplay between the different stories of quantum physics shows how the science not only shapes the stories: the stories shape the science, too.

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Acknowledgements

First of all, I would like to thank my supervisors. In *George and the Big Bang*, one of the case studies in this thesis, the evil Professor Zuzubin is so frustrated with the success of his PhD student that he hides a bomb in the Large Hadron Collider to blow up all the physicists in the world. If for every evil Zuzubin there's a supervisor who is his polar opposite, we should check the LHC for another bomb. Professor Sally Shuttleworth and Dr Michael Whitworth are amazing, supportive supervisors who created the perfect environment for my research to thrive. I hope that one time soon all DPhils will be able to benefit from having two supervisors.

To quote SF researcher Tom Shippey, 'One of the problems with live authors, apart from them appearing in the flesh to contradict you, is that they will keep on writing.' Professor Kirsten Shepherd-Barr arranged for me to meet Philip Pullman in the flesh to contradict and correct me; he has given me the kinds of valuable insights that make me particularly pleased to work with contemporary authors. Social media put me in touch with David Walton, who did the same, and with Jenny Hogan, who sent me Otto Fong's *The Quantum Bunny* all the way from Singapore.

I am grateful to friends and family both here and abroad. My parents, Prem and Joyce Dihal, and my brother, Arun. Sonja and Wieteke – *tous pour une, une pour tous*. Familie Sjaalmans. The St Anne's MCR, for distracting me at (mostly) appropriate times, in particular Matthew Gracey-McMinn, Karamvir Chadha, Graham Benham, and Nicole Eichert. Alice Kelly compensated for these distractions: a significant part of my thesis was produced at her Academic Writing Group. Franziska Kohlt helped me navigate Oxford and gave invaluable advice on all things Alice in Wonderland. I am a better writer thanks to Leah Broad and Laura Ludtke, who let me write for the *Oxford Culture Review* and the *Oxonian Review*.

The St Anne's College Library, staffed with the most dedicated librarians – David Smith, Clare White, Sally Speirs and Catherine Hartley – provided me with research and teaching materials. My academic writing has benefited from excellent proofreaders: Caspar van Deursen, Nele Pol-latschek, Noreen Masud, Alison Moulds, Leah Broad, Laura Ludtke, Sonja Kleij, and Alexis Brown. Several physicists scrutinised my explanations, inferences and cognitive leaps: Lex van Deursen, Pauline van Deursen, Paweł Biernacki, Patricia Contreras Tejada, and Anna Pearson. Professor David Wallace kindly allowed me to attend his Everett seminars, and the lecturers at the Physics Faculty allowed me to sit in and not feel out of place *at all* on the undergraduate physics lectures. I would not have gone to Oxford without the support from Professor Frans-Willem Korsten, who supervised my master's dissertation.

My research was funded by the St Anne's College Iris Murdoch Graduate Research Scholarship, a Prins Bernhard Cultuurfonds Fellowship, and grants from the Hendrik Muller Fonds and the Fundatie van de Vrijvrouwe van Renswoude. My research was hindered by the University of Oxford Disability Service, which got back to me two years after I asked them for help.

No cats were hurt in the making of this thesis.

Caspar, though, had to move to the UK. I'm sorry. This one is for you.

Introduction

The last century was defined by physics. From the minds of the world's leading physicists there flowed a river of ideas that would transport mankind to the very pinnacle of wonder and to the very depths of despair. This was a century that began with the certainties of absolute knowledge and ended with the knowledge of absolute uncertainty. It was a century in which physicists developed theories that would deny us the possibility that we can ever properly comprehend the nature of physical reality. It was also a century in which they built weapons with the capacity utterly to destroy this reality.

Thus opens Jim Baggott's quantum physics popularization *The Quantum Story*.¹ Its title suggests the existence of a single authoritative narrative of quantum physics. Yet his work is one of dozens of very different quantum stories that have been published since the inception of quantum physics in the early twentieth century. Some of these accounts strongly disagree with each other concerning the validity of the ideas the first quantum physicists had introduced. Others place less emphasis on the destructive powers of the technological applications of particle physics, because they are written for children, for instance. Some fictional quantum stories have taken the concepts Baggott introduces and extrapolated them to an age in which humankind understands quantum theory better – and where meddling with it can have life-threatening consequences.

This thesis explores the stories of quantum physics, with an emphasis on the plural. It investigates a range of narratives about quantum physics published for non-expert audiences. Quantum physics was first explained to lay readers in nonfictional popular accounts, and soon entered the fictional realm as its narrative potentialities

¹ Jim Baggott, *The Quantum Story: A History in 40 Moments* (2011; repr., Oxford: Oxford University Press, 2016), xiii.

inspired science fiction writers in particular. Fictional and nonfictional stories of quantum physics thus exist alongside each other, both influencing the public perception of science. So far, there has been very little research which has addressed works across the fictional and non-fictional divide. I address this gap by investigating a wide range of narratives that are woven around quantum physics for non-physicists: both fictional and nonfictional stories, for a readership that ranges from children to adults. I investigate which stories have been told about quantum physics, why these in particular have been selected, by whom they were written, and to what purpose. Investigating how the narratives of various interpretations of quantum physics have developed shows the interplay between physics itself and the public perception of physics. This introductory chapter surveys previous studies of quantum physics in the fields of literature and science, science fiction, and science communication, and their respective methodologies. As well as introducing key terms, definitions, and scientific principles, the chapter outlines the limitations and boundaries of my research, and situates this research at the intersections of these three fields.

Quantum mechanics developed in the early twentieth century as a field that investigated interactions at atomic and subatomic scales. The starting date of this research is dictated by the publication of Max Planck's 1900 paper 'Zur Theorie des Gesetzes der Energieverteilung im Normalspektrum,'² in which Planck coined the term 'quantum' for the smallest possible physical entity. The development of these theories by Planck and his successors marked a watershed in the history of physics. The combination of the developments of relativity and quantum mechanics led to an explosive

² Max Planck, 'Zur Theorie des Gesetzes der Energieverteilung im Normalspektrum (On the Theory of the Energy Distribution Law of the Normal Spectrum)', *Verhandlungen der Deutschen Physikalischen Gesellschaft im Jahre 1900* 2 (1900): 237–45.

growth of popularizations in the early twentieth century, during which the newest developments in physics were communicated to the public even before they were entirely understood by the scientific community.³ J.W.N. Sullivan's 1923 popularization *Atoms and Electrons*, for instance, introduced Planck's quantum theory, even though at the time of writing it was still 'in many respects, little understood [...]. It is still attended with very grave difficulties.'⁴ The term 'quantum,' however, remained rarely used in the titles of non-technical books until the 1980s, when suddenly the term exponentially increased in popularity, to the extent that it was even used in the titles of books that had nothing whatsoever to do with physics.⁵

I shall focus on quantum physics specifically, rather than on physics as a whole. My goal is to investigate the cultural manifestations of the unresolvedness of quantum physics. Quantum physics is thoroughly tested and yet still not fully understood; moreover, several well-developed interpretations have coexisted for decades. This situation makes quantum physics unique within physics as a whole, and an important field of investigation: unlike relativity, for instance, some tenets of quantum physics are inherently untestable, such as the existence of multiple universes. Authors must negotiate these alternative interpretations, either allowing them into the narrative or choosing to present a partial picture.

The terms 'quantum physics' and 'quantum mechanics' refer to the same scientific field. The former is preferred in popularizations; the latter, as a technically more

³ The development of popularizations of relativity is addressed in Michael H. Whitworth, *Einstein's Wake: Relativity, Metaphor, and Modernist Literature* (Oxford: Oxford University Press, 2001) and Katy Price, *Loving Faster than Light: Romance and Readers in Einstein's Universe* (Chicago: University of Chicago Press, 2012).

⁴ J.W.N. Sullivan, *Atoms and Electrons* (London: Hodder and Stoughton, 1923), 118.

⁵ Elizabeth Leane, 'Contemporary Popular Physics: An Interchange between Literature and Science' (DPhil thesis, University of Oxford, 1999), 50.

correct term – mechanics being that field of science which is concerned with the interactions of physical bodies when subjected to forces – is favoured in scientific papers and textbooks. In this thesis, ‘quantum mechanics’ is reserved for discussions of the works that use this term, to prevent confusion; ‘quantum physics’, as the more widely known term, is used in all other cases.

Developments in quantum physics throughout the century were soon both popularized and adopted in literary works, even though communication to non-experts was hindered by the abstract nature of the new concepts. Perhaps owing to the complexity of the scientific material, little research has been done on the communication of quantum physics in any medium or genre, a notable exception being the work of Marie-Laure Ryan.⁶ In contrast, a significant body of work has covered relativity, including the works discussed below by Whitworth, Price, and Ebury.⁷

In the thesis, the term ‘popularizations’ is meant to encompass those works that are not intended to be used in the lecture hall or classroom as textbooks. Although the term ‘popularizations’ is problematic because of its implications of ‘dumbing down’ and ‘vulgarization’, the term is the most readily available shorthand for such books. The term ‘non-technical’ is sometimes used as a synonym for popularizations for adults, but this term is problematic for children’s books: both school books and home books are ‘non-technical’ compared to the texts used by professionals.

⁶ Marie-Laure Ryan, *Possible Worlds, Artificial Intelligence, and Narrative Theory* (Bloomington: Indiana University Press, 1991); Marie-Laure Ryan, ‘From Parallel Universes to Possible Worlds: Ontological Pluralism in Physics, Narratology, and Narrative’, *Poetics Today* 27, no. 4 (1 December 2006): 633–74, <https://doi.org/10.1215/03335372-2006-006>; Marie-Laure Ryan, ‘Narrative/Science Entanglements: On the Thousand and One Literary Lives of Schrödinger’s Cat’, *Narrative* 19, no. 2 (2011): 171–86, <https://doi.org/10.1353/nar.2011.0007>.

⁷ Whitworth, *Einstein’s Wake*; Price, *Loving Faster than Light*; Katherine Ebury, *Modernism and Cosmology: Absurd Lights* (Houndmills: Palgrave Macmillan, 2014).

The thesis is constructed around a series of case studies of book-length works. Chapters 1, 2, 3 and 6 each investigate a different narrative form for adults: selective popularization; explicit conflict with other popular science authors; popularizations with a fictional storyline; and the influence of quantum physics on the narrative structure of fictional works. The case studies are taken from a broad temporal range, 1900 to the present, in order to comment on changing and continuous trends. The works selected as case studies represent the debates that surround quantum physics with respect to its unresolved status, the abstractness and difficulty of communicating its principles, and the necessity of selecting one out of a multiplicity of interpretations. Chapter 4, on popularizations for children, analyses three pre-existing narratives that have been adapted as a framework for the communication of quantum physics. The works by Madeleine L'Engle and Philip Pullman, in Chapter 5, on children's fiction, are selected based on their complementarity: both make use of modern physics, one to construct a positive narrative about religion, the other to criticize its institutionalization.

The primary texts investigated in the thesis unfortunately display a strong gender and ethnicity bias. All authors discussed are white; only three are women: Madeleine L'Engle, Lucy Hawking, and Andre Norton. Of these three, Hawking is a co-author, and Norton published under a masculine pseudonym. This problem of representation is part of a larger issue in both physics and science fiction, which are still white-male-dominated fields. Even in the twenty-first century, less than 25% of US and UK undergraduate physics degrees are awarded to women, and only 10% to 'minorities'.⁸ The

⁸ APS, IPEDS, NSF, 'Percentage of Women in Physics', APS Physics, accessed 19 February 2017, <https://www.aps.org/programs/education/statistics/womenphysics.cfm>; APS, IPEDS, 'Percentage of Degrees Awarded to Minorities', APS Physics, accessed 19 February 2017, <https://www.aps.org/programs/education/statistics/minoritydegrees.cfm>; Sean McWhinnie, 'Physics Students in UK Higher Education Institutions' (Oxford: Institute of Physics, March 2012), 7, http://www.iop.org/publications/iop/2012/file_54949.pdf.

limited access women and minorities have to quantum physics knowledge may be a reason for the dearth of such writers who use this science. Science fiction has long been a field so male-dominated that authors such as Alice Norton (Andre Norton) and Alice Sheldon (James Tiptree, Jr.) resorted to masculine pseudonyms to facilitate the publication of their prizewinning works. Although Philip Pullman, Madeleine L'Engle, and Blake Crouch prove that one does not need a physics degree in order to make use of quantum physics in fiction, most science fiction authors discussed in the thesis have a science background that facilitates the implementation of scientific topics in their writing.

Studies that bring together the humanities and the exact sciences almost without exception mention C.P. Snow's lecture 'The Two Cultures', in which Snow expressed his frustration that as an author and scientist he seemed to be one of very few people to bridge the gap between the literary and scientific cultures.⁹ Charlotte Sleigh's description of Snow's importance today succinctly summarizes my own views: 'Snow and his 1959 lecture on the "two cultures" is an obligatory but uninspiring inclusion in any introduction to the field of literature and science.'¹⁰ Snow's lecture, and F.R. Leavis's vitriolic response, are now remembered as a public fight between experts, similar to the conflicts analysed in Chapter 2.¹¹ Snow's 'two cultures' concept is not part of my analytical framework, but is still in wide circulation in the English-speaking world.¹²

⁹ C.P. Snow, 'The Two Cultures', *New Statesman*, 10 June 1956, <http://www.newstatesman.com/cultural-capital/2013/01/c-p-snow-two-cultures>.

¹⁰ Charlotte Sleigh, *Literature and Science* (Basingstoke: Palgrave Macmillan, 2010), 5.

¹¹ F. R. Leavis, *The Two Cultures? The Significance of C.P. Snow*, ed. Stefan Collini (1962; repr., Cambridge: Cambridge University Press, 2013).

¹² Leane, 'Contemporary Popular Physics', i; Stefan Collini, 'Introduction', in *The Two Cultures? The Significance of C.P. Snow*, by F. R. Leavis (Cambridge: Cambridge University Press, 2013), 1-49, p. 3.

The continuation of references to Snow's lecture in contemporary popular science, including in works analysed in this thesis, reinforces an outdated model of the relations between literature and science.¹³

In previous scholarship, the connections between narrative and science have been studied in three separate fields that interact very little: literature and science, science fiction, and science communication. Works for children have been unduly neglected in all three fields. The intersections and influences of stories across genres, authorial intentions and intended audiences are thus underappreciated, since the simultaneous existence of these stories is not acknowledged or explored.

Science Fiction Studies

The latest scientific developments often enter popular culture through science fiction almost as quickly and elaborately as through popularization. Isaac Asimov and Arthur C. Clarke are best known for their science fiction, but they also published popularizations; Fred Hoyle, John Gribbin, and Patrick Moore are best known as science popularizers, but also published science fiction.¹⁴

The term 'science fiction' has proven notoriously undefinable, in spite of the immediate associations it evokes, and most critics avoid the question of definition.¹⁵ The

¹³ See e.g. Ben Miller, *It's Not Rocket Science* (London: Sphere, 2012), 42; Alastair I. M. Rae, *Quantum Physics: Illusion or Reality?* (Cambridge: Cambridge University Press, 1986), 96.

¹⁴ Examples of Asimov's and Clarke's popularizations include Isaac Asimov, *How Was the Universe Born?* (London: Gareth Stevens Children's Book, 1989); Arthur C. Clarke, *Interplanetary Flight: An Introduction to Astronautics* (London: Temple Press, 1950); SF written by Hoyle, Gribbin, and Moore includes Fred Hoyle, 'October the First Is Too Late', in *Three Classic Novels* (1966; repr., London: Gollancz, 2016), 253–423; John Gribbin and Douglas Orgill, *The Sixth Winter* (New York: Simon and Schuster, 1979); Patrick Moore, *Mission to Mars* (London: Burke, 1955).

¹⁵ Tom Shippey, 'Preface: Learning to Read Science Fiction', in *Fictional Space: Essays in Contemporary Science Fiction*, ed. Tom Shippey (Oxford: Basil Blackwell, 1991), 1–33, p. 1; David Seed, ed., 'Introduction: Approaching Science Fiction', in *A Companion to Science Fiction* (Oxford: Blackwell, 2008), 1–7, p. 7; Mark Bould et al., eds., *The Routledge Companion to Science Fiction* (London: Routledge, 2009), xix;

genre tends to be divided into ‘soft’ and ‘hard’ science fiction, with the latter being the subgenre most relevant for the thesis. David Seed explains that ‘hard’ science fiction was first devised as a subgenre that was intended ‘as a means of promoting scientific knowledge.’¹⁶ This claim was first made by Hugo Gernsback in his *Amazing Stories*: the stories were supposed to be ‘always instructive.’¹⁷ This instructive intention, however, does not imply that the works aim to educate the reader about specific scientific concepts; rather, one could see this genre as attempting to convey general knowledge about the potential science has for transforming human lives.

Three key characteristics of science fiction are particularly relevant to the thesis: the novum, cognitive estrangement, and extrapolation. In his seminal work *Metamorphoses of Science Fiction: On the Poetics and History of a Literary Genre* (1979), Darko Suvin claims that the defining aspect of science fiction is a concept called the ‘novum’:

the hegemonic literary device of a *locus* and/or *dramatis personae* that (1) are radically or at least significantly different from the empirical times, places, and characters of ‘mimetic’ or ‘naturalist’ fiction, but (2) are nonetheless – to the extent that SF differs from other ‘fantastic’ genres [– ...] simultaneously perceived as *not impossible* within the cognitive (cosmological and anthropological) norms of the author’s epoch.¹⁸

The novum was later more narrowly redefined by Tom Shippey: ‘a discrete piece of information recognizable as not-true, but also as not-unlike-true, not-flatly- (and in the current state of knowledge) impossible.’¹⁹ An extrapolation of the scientific status quo

David Seed, *Science Fiction: A Very Short Introduction* (Oxford: Oxford University Press, 2011), 1; Brian Baker, *Science Fiction: Reader’s Guides to Essential Criticism* (London: Palgrave Macmillan, 2014), 7.

¹⁶ Seed, *Science Fiction*, 1.

¹⁷ Hugo Gernsback, ‘A New Sort of Magazine’, *Amazing Stories* 1, no. 1 (April 1926): 3.

¹⁸ Darko Suvin, *Metamorphoses of Science Fiction: On the Poetics and History of a Literary Genre*, ed. Gerry Canavan (1979; repr., Bern: Peter Lang, 2016), 2. Emphases in original.

¹⁹ Shippey, ‘Learning to Read Science Fiction’, 9.

can be used as a novum. Science fiction, Seed writes, is an ‘embodied thought experiment.’²⁰ Science fiction presents situations and technologies of varying scientific plausibility in order to explore the implications they have for human lives. The narratives function as a testing ground for the way in which human nature would respond to these situations.

In *Metamorphoses*, Suvin also defines science fiction as ‘the literature of cognitive estrangement’. He takes the term ‘estrangement’ from Brecht (*Verfremdungseffekt*), who defined it as ‘[a representation] which allows us to recognize its subject, but at the same time makes it seem unfamiliar.’ The cognitive aspect of science fiction, seeing ‘the norms of any age, including emphatically its own, as unique, changeable’, differentiate science fiction from genres based on fixed, supernaturally determined human relations, such as myth and fantasy.²¹ Shippey explains that “‘Estrangement’ [...] means recognising the novum; “cognition” means evaluating it, trying to make sense of it.’²² Recent scholarship has criticized Suvin’s emphasis on literature in this definition, as he omits all other media from his analysis.²³ The concept of cognitive estrangement itself, however, is relevant in discussions of both fictional and nonfictional stories of quantum physics, in which quantum physics is presented as an entirely new way to look at the world.

Extrapolations of quantum physics are used as nova in the science fiction discussed in the thesis: Greg Egan presents a protagonist who can control the collapse of

²⁰ Seed, *Science Fiction*, 2.

²¹ Suvin, *Metamorphoses of Science Fiction*, 15, 18, 19.

²² Shippey, ‘Learning to Read Science Fiction’, 13.

²³ Rob Latham, ‘Introduction’, in *The Oxford Handbook of Science Fiction*, ed. Rob Latham (Oxford: Oxford University Press, 2014), 1–19, p. 2.

the wavefunction in *Quarantine* (1992), and Blake Crouch locates his narrative in several parallel universes in *Dark Matter* (2016).²⁴ Suvin's definition of the novum is rather too restrictive for these events, which sound entirely impossible within any cognitive norms. However, authors such as Egan and Crouch aim to prevent an outright dismissal of their nova by informing the reader explicitly that their scenarios are based on quantum physics, thus grounding the events in real-world science. The reader is made to question the status of the novum as outright impossible *because* of its connection to quantum physics.

Science fiction studies has at times adopted terminology from the shorthand employed by writers and fans. Part of the critical vocabulary of the field might therefore sound unsophisticated to an outsider: 'infodump', for instance, is a term that might not be taken seriously at first sight. However, this is a valid term in science fiction criticism, used to describe 'a large amount of background information inserted into a story all at once'.²⁵ The infodump denotes a point at which the science fiction work comes particularly close to resembling a popular science work. In science fiction that makes use of quantum physics, the infodump is where the author reveals which interpretation is adhered to, and what quantum physics makes possible in the story world.

²⁴ Greg Egan, *Quarantine* (London: Legend, 1992); Blake Crouch, *Dark Matter* (London: Macmillan, 2016).

²⁵ Jeff Prucher, ed., 'Infodump', *The Oxford Dictionary of Science Fiction* (Oxford: Oxford University Press, 2006), <http://www.oxfordreference.com/view/10.1093/acref/9780195305678.001.0001/acref-9780195305678-e-317>.

Literature and Science

The field of literature and science has had a long-standing interest in those theories of metaphor that were first developed within philosophy of science.²⁶ Mary Ellen Pitts points out that the arrival of the new physics undermined many of the stock metaphors of science.²⁷ At the same time, the new physics posited issues so complex that the powers of visualization inherent in metaphor were stretched to their limits in attempts to depict the processes of quantum physics.²⁸ Some authors resorted to encapsulating their entire book-length exposition in an overarching fantasy narrative from which all explanatory metaphors and analogies were derived, a process discussed in Chapter 3.

Several studies of literature and science focus on twentieth-century physics and literature in particular. Michael H. Whitworth's *Einstein's Wake* (2001), Katy Price's *Loving Faster than Light* (2012), and Katherine Ebury's *Modernism and Cosmology* (2014) all address the modernist period. Ebury investigates the enormous changes cosmology underwent from the 1887 Michelson-Morley experiment onwards, and the influence this radically new cosmology had on the works of Yeats, Joyce, and Beckett. The paradigm shift she describes is similar to the one quantum physics would instigate in the 1920s, after which the science one learned at school was at odds with the scientific status quo, and popular texts became a means for literary authors to learn about the new science.

²⁶ Max Black, *Models and Metaphors: Studies in Language and Philosophy* (Ithaca, NY: Cornell University Press, 1962); Mary B. Hesse, *Models and Analogies in Science* (London: Sheed & Ward, 1963).

²⁷ Mary Ellen Pitts, 'Reflective Scientists and the Critique of Mechanistic Metaphor', in *The Literature of Science: Perspectives on Popular Scientific Writing*, ed. Murdo William McRae (Athens, GA: University of Georgia Press, 1993), 249–72.

²⁸ Paul Ricoeur, 'The Metaphorical Process as Cognition, Imagination, and Feeling', in *On Metaphor*, ed. Sheldon Sacks (Chicago: University of Chicago Press, 1979), 141–57.

Whitworth investigates modernist fiction and its relations to contemporaneous developments in physics, in particular the theories of relativity. Focusing on the existence of similar metaphors in both literature and science, he studies literary periodicals, in which the authors subject to his investigation published their literary theory and criticism. Whitworth chose to focus on periodicals in order to trace metaphors in specific social circles, those of high modernism; I have chosen to take a longer view that goes beyond specific social networks both geographically and temporally, and to focus specifically on narrative structure within book-length texts. Periodical articles therefore inform my analysis, but are not the focus of discussion. The simultaneous usage of certain metaphors in both fiction and quantum physics is, however, relevant for the thesis, and will be investigated as part of larger bodies of writing, including book-length popularizations as well as literary texts.

Price investigates popular writing on Einsteinian relativity in the modernist period, revealing how journalists and readers alike struggled to comprehend the strange new science of relativity, a struggle that is seen again in popular works on quantum physics.²⁹ Price investigates those instances when scientific knowledge was playfully appropriated when relativity entered the realm of popular entertainment. The works they look at, therefore, are not considered 'popular science writing' in the sense I use it in the thesis, meaning works that are written with an educational intention. This thesis does not investigate jokes and satire, as Price does; the popular science works I discuss sought to convey a sense of factuality and objectivity, even though the science itself was unresolved and internally conflicting.

²⁹ Price, *Loving Faster than Light*.

In the one book-length study of quantum physics from a literature and science perspective, *Reading Popular Physics* (2007), Elizabeth Leane focuses on the communication of modern physics in popular science books written between 1970-1990.³⁰ Leane does not discuss fiction, singling out popularizations as the focus of her research, in order to emphasize their importance as a cultural interface: they mediate stylistically and conceptually between literature and science. Responding to a dearth of research in popular science from a literary studies perspective, Leane takes into account a broad range of topics, including chaos theory and the intersections of science and New Age spirituality. Various researchers, whose work I discuss below, have looked at popular science, fiction, or works for children separately; I bring such research together in a consideration of a narrower subtopic of physics, quantum theory, but look at a broader range of material, including children's books and (science) fiction.

I have elsewhere commented on the unexpected and undesirable separateness of the academic fields of science fiction and literature and science.³¹ Many literature and science scholars either omit any reference to, or deliberately distance themselves from, science fiction. The works that do include science fiction tend to present this field as separate from the main focus of the work. For instance, John H. Cartwright and Brian Baker note in the 'Preface' to their 2005 survey volume *Literature and Science: Social Impact and Interaction* that

we have traced the connection between science and 'great works' of literature, to the exclusion of minority voices. [...] the focus upon the Gothic and science

³⁰ Elizabeth Leane, *Reading Popular Physics: Disciplinary Skirmishes and Textual Strategies* (Hampshire: Ashgate, 2007).

³¹ Kanta Dihal, 'On Science Fiction As a Separate Field', *Journal of Literature and Science* 10, no. 1 (30 June 2017): 32-36, <https://doi.org/10.12929/jls.10.1.07>.

fiction in chapters eight, nine, and ten will, we hope, give some insight into the links between science and popular genres.³²

The way Cartwright and Baker have chosen to focus on ‘great works’, with science fiction as a secondary consideration, comes as a surprise to the reader who is familiar with Baker’s work in science fiction studies.³³ In 2008 Sharon Ruston included an essay by Baker on ‘Evolution, Literary History and Science Fiction’ in her *Literature and Science*; however, she does not mention any previous science fiction research, and presents the study of literature and science as a young field.³⁴

In 1990, Tom Shippey acknowledged his academic colleagues’ resistance to science fiction, claiming that it was due to ‘the existence in science fiction of the novum, and of the pattern of intellectual inference to be drawn from it. [...] You need [to both recognize and evaluate the novum] to read science fiction. Some people are willing to do neither.’³⁵ Shippey initially conveys a mocking sense of superiority over his colleagues, claiming that professional readers – academics, critics – are unwilling to perform the particular efforts that science fiction fans engage in as a matter of course. However, his focus on the novum exposes an important difference between the fields of science fiction studies and literature and science. The novum, Shippey claims, has grabbed all critical attention, leaving too little focus on ‘the special problems [...] of authorial rhetoric and reader response’.³⁶ Having not engaged enough with several of the

³² John Cartwright and Brian Baker, *Literature and Science: Social Impact and Interaction* (Santa Barbara, CA: ABC-CLIO, 2005), xviii.

³³ E.g. Baker, *Science Fiction: Reader’s Guides to Essential Criticism*.

³⁴ Brian Baker, ‘Evolution, Literary History and Science Fiction’, in *Literature and Science*, ed. Sharon Ruston (Woodbridge: D. S. Brewer, 2008), 131–50; Sharon Ruston, ‘Introduction’, in *Literature and Science*, ed. Sharon Ruston (Woodbridge: D. S. Brewer, 2008), 1–12, p. 7.

³⁵ Shippey, ‘Learning to Read Science Fiction’, 13.

³⁶ Shippey, 31.

most important themes in contemporary literary criticism, science fiction studies has come to be considered an outlier field.

Science Communication

Science communication studies developed in the 1980s, partially in response to political pressure. Jane Gregory describes how in the UK, the Royal Society lobbied the government after one of their reports showed that the country was losing scientists to other countries: ‘according to some scientists, a major factor in this situation was that society simply did not value science because the public did not know much about it.’³⁷ A 1988 science survey of the British public, in which a large percentage of respondents failed to correctly answer extremely basic science questions, reinforced the views of scientists who characterized non-scientists as suffering from a deficit of scientific knowledge.³⁸ In 1990, Stephen Hilgartner described ‘the culturally dominant view of the popularization of science’ that had developed from attempts to improve this situation as a two-stage model in which ‘first, scientists develop genuine scientific knowledge; subsequently, popularizers disseminate simplified accounts to the public.’³⁹ This view is also known as the ‘deficit model’ of ‘public understanding of science’ (PUS), ‘in which scientists and laypeople differ by virtue of the scientific knowledge they have’.⁴⁰ In this model, which is based on the Mertonian model of science, certain

³⁷ Jane Gregory, ‘Understanding “Science and the Public”: Research and Regulation’, *Journal of Commercial Biotechnology* 10, no. 2 (December 2003): 131–39, p. 131.

³⁸ Gregory, p. 132.

³⁹ Stephen Hilgartner, ‘The Dominant View of Popularization: Conceptual Problems, Political Uses’, *Social Studies of Science* 20, no. 3 (1990): 519–39, p. 519.

⁴⁰ Jane Gregory and Simon Jay Lock, ‘The Evolution of “Public Understanding of Science”: Public Engagement as a Tool of Science Policy in the UK’, *Sociology Compass* 2, no. 4 (July 2008): 1252–65, <https://doi.org/10.1111/j.1751-9020.2008.00137.x>.

scientific knowledge must be communicated to a passive audience that lacks such knowledge, because it is deemed to be important to them.⁴¹ This field understands science communication as a form of translation intended to fill knowledge gaps identified in the general public.

PUS was later criticized for its view of science communication as a one-way process, which insists that non-experts *should* know a particular thing without questioning what they *want* to know. The more recent view of popularization has shifted to a participatory model, usually described as ‘public engagement with science and technology’ (with the equally awkward acronym PEST), in which, as Jane Gregory describes it, ‘the public are seen as active participants in democratic and personal decisions about science.’⁴² Unlike PUS, PEST acknowledges an intersection between the concerns, values and knowledge of scientists and non-scientists alike, which meet in policymaking.⁴³ The changed perception of the general public as an active agent in science policymaking has raised a sense of urgency in some quantum physicists, who now wish to convince this public, as well as their scientific peers, that their particular interpretation of quantum physics is correct.

Science communication studies emerged from within the social sciences, which partly explains its limited engagement with fiction. Works that address literary tropes

⁴¹ Michel Cloître and Terry Shinn, ‘Expository Practice: Social, Cognitive and Epistemological Linkage’, in *Expository Science: Forms and Functions of Popularisation*, ed. Terry Shinn and Richard Whitley (Dordrecht: D. Reidel Publishing Company, 1985), 31–60.

⁴² Jane Gregory, ‘Public Understanding of Science: Lessons from the UK Experience’, SciDev.Net, 12 March 2001, <http://www.scidev.net/index.cfm?originalUrl=global/communication/feature/public-understanding-of-science-lessons-from-the.html>.

⁴³ Gregory and Lock, ‘The Evolution of “Public Understanding of Science”’.

in popular science writing, such as those by Beer, McRae and Leane, are usually positioned within the field of literature and science.⁴⁴ In the early twenty-first century, science communication researchers actively began to investigate the intersections of science fiction and science communication, with a particular emphasis on film as a medium for science communication.⁴⁵ Investigations of science fiction literature as a means of communicating science have as yet been scarce.

Children's Books

Alice in Wonderland is one of the very few children's books that has been studied in a literature and science context.⁴⁶ As various introductions to literature and science show, the study of children's literature within this field is rare: Peterfreund, Sleight, Clarke and Rossini, and Willis do not cover children's literature at all.⁴⁷ Neither Whitworth, nor Price, nor Leane includes a discussion of children's books. Their focus on works for adults is partly determined by the time period they focus on: quantum phys-

⁴⁴ Gillian Beer, *Darwin's Plots: Evolutionary Narrative in Darwin, George Eliot and Nineteenth-Century Fiction*, 1983. 2nd ed. (Cambridge: Cambridge University Press, 2000); Murdo William McRae, ed., *The Literature of Science: Perspectives on Popular Scientific Writing* (Athens, GA: University of Georgia Press, 1993).

⁴⁵ David A. Kirby, 'Scientists on the Set: Science Consultants and the Communication of Science in Visual Fiction', *Public Understanding of Science* 12, no. 3 (1 July 2003): 261–78, <https://doi.org/10.1177/0963662503123005>; Luciano Guillermo Levin and Daniela De Filippo, 'Films and Science: Quantification and Analysis of the Use of Science Fiction Films in Scientific Papers', *Journal of Science Communication* 13, no. 3 (2014): 1–20; Hyo Jin Kim, 'Discovering Science Fiction Fandom in Science Communication and Science Culture: A Case Study of Doctor Who Fandom in South Korea' (Texas Tech University, 2014), <http://hdl.handle.net/2346/58716>.

⁴⁶ Melanie Keene, *Science in Wonderland: The Scientific Fairy Tales of Victorian Britain* (Oxford: Oxford University Press, 2015); Gillian Beer, *Alice in Space: The Sideways Victorian World of Lewis Carroll* (Chicago: University of Chicago Press, 2016).

⁴⁷ Stuart Peterfreund, ed., *Literature and Science: Theory & Practice* (Boston, MA: Northeastern University Press, 1990); Sharon Ruston, ed., *Literature and Science* (Woodbridge: D. S. Brewer, 2008); Sleight, *Literature and Science*; Bruce Clarke and Manuela Rossini, eds., *The Routledge Companion to Literature and Science* (New York: Routledge, 2011); Martin Willis, *Literature and Science: Readers' Guides to Essential Criticism* (London: Palgrave Macmillan, 2015).

ics popularizations for children started to appear twenty years after a surge in publications for adults, so it seems likely that the earliest relativity popularizations for children appeared after the modernist period. Ruston does mention children's literature in her own essay in her edited collection, but not in the Introduction.⁴⁸ One wonders whether, like science fiction, children's literature is not taken seriously enough, and therefore omitted from the literature and science discipline.⁴⁹ Literature and science studies that do engage with children's books, such as Melanie Keene's *Science in Wonderland* (2015), tend to focus on children's books alone, so that the intersections and common themes in works for adults and children remain unacknowledged and unexplored. Keene focuses on popular scientific writing for children in the nineteenth century, revealing narrative structures that, as this thesis shows, continue to be used in the twentieth and twenty-first centuries in works for both age groups. Studies of science fiction for children are similarly scarce, one exception being Farah Mendlesohn's *The Inter-Galactic Playground*; this work is unique, moreover, in including an analysis of popular science books for children to contextualize the trends in science fiction.⁵⁰ Within science communication studies, one relevant study of popular science books for children is Alice Bell's PhD thesis *Science as Pantomime* and its related article 'Science as "Horrible"'.⁵¹ Her research explores the *Horrible Science* series (2005-present) by

⁴⁸ Sharon Ruston, 'Natural Rights and Natural History in Anna Barbauld and Mary Wollstonecraft', in *Literature and Science*, ed. Sharon Ruston (Woodbridge: D. S. Brewer, 2008), 53–71, pp. 61–63; Ruston, 'Introduction'.

⁴⁹ Margaret Kean and Diane Purkiss warn in their Children's Literature syllabus for third-year undergraduates at the University of Oxford (2016) that 'most CL criticism is written by and for educationalists and librarians, and is often not terribly sophisticated. [...] you will also notice a much higher incidence of minor factual error than would be tolerated in Shakespeare studies', suggesting that there may be some justification in not taking all children's literature criticism completely seriously.

⁵⁰ Farah Mendlesohn, *The Inter-Galactic Playground: A Critical Study of Children's and Teens' Science Fiction* (Jefferson, NC: McFarland & Co, 2009).

⁵¹ Alice Bell, 'Science as Pantomime: Explorations in Contemporary Children's Non-Fiction Books' (Imperial College, 2008); Alice Bell, 'Science as "Horrible": Irreverent Deference in Science Communication',

Nick Arnold and Tony De Saulles, a children's book series that covers a wide range of scientific topics, although to this date no *Horrible Science* book has covered quantum physics. Bell's thesis will be discussed further in Chapter 4.

My thesis addresses works for both age groups: the sheer fact that there are children's books that engage with quantum physics is worth investigating by itself. Quantum physics is described in books for adults as mind-boggling, brain-bending and essentially incomprehensible, phrases which attempt to impress, but also to comfort the reader for not understanding completely. Yet Russell Stannard, Otto Fong, and Lucy and Stephen Hawking explain quantum physics to a primary-school audience, while Philip Pullman and Madeleine L'Engle make explicit use of quantum physics in their novels. When quantum physics is presented to adults as ungraspably difficult, while it is at the same time taught informally to children, a study that brings both kinds of stories together sheds a new light on the public perceptions of quantum physics.

My thesis draws on works across all age groups to argue that similar narrative tropes have been applied in writing about quantum physics in popular science and in fiction, so that the two genres mutually influence and reinforce what physicists and non-physicists alike understand quantum physics to be. As I establish by means of a series of case studies, public understanding differs significantly from the professional understanding of quantum physics as taught at the undergraduate level and above. The literary devices that are common more generally in science popularization, such as metaphors and analogies, become more strongly emphasized in the case of quantum physics.

Quantum physics is an unusual scientific field. Modern technologies such as lasers, semiconductors, solar panels and MRI scanners all function by means of quantum processes. Yet in spite of its successful applications, the underlying principles of the field are still not understood. New rival interpretations of the underlying mechanics have continued to be framed alongside existing older ones. Three prominent interpretations and the stories they have engendered are explored in detail in the thesis: the Copenhagen, conscious collapse, and many-worlds interpretations. These interpretations are empirically equivalent in the Kuhnian sense: they all give identical predictions for all quantum physics experiments performed to this date.⁵² Since so far no experiment has been able to distinguish between them, these interpretations are underdetermined, meaning that adherents of each interpretation have to resort to discussion and argumentation, rather than empirical evidence, in order to attain both scientific and public prominence. Many influential physicists have published popular physics books in which they express a personal preference for one of these interpretations and argue against others. I will show that these popular works play a central role in the conflict: popular works do not simply report the scientific status quo, they can also influence science itself.

It has become a habit at quantum physics conferences to record the popularity of the different interpretations of quantum physics; several of these tallies have been published.⁵³ These surveys show that the majority of quantum physicists continue to

⁵² Max Tegmark, 'The Interpretation of Quantum Mechanics: Many Worlds or Many Words?', *Fortschritte der Physik* 46, no. 6–8 (1998): 855–62, p. 860.

⁵³ Christoph Sommer, 'Another Survey of Foundational Attitudes towards Quantum Mechanics', *ArXiv Preprint*, 2013, <https://arxiv.org/abs/1303.2719>; Travis Norsen and Sarah Nelson, 'Yet Another Snapshot of Foundational Attitudes toward Quantum Mechanics', *ArXiv Preprint*, 2013, <https://arxiv.org/abs/1306.4646>; Maximilian Schlosshauer, Johannes Kofler, and Anton Zeilinger, 'A

pledge allegiance to the oldest of all quantum physics interpretations, the Copenhagen interpretation.

The Copenhagen Interpretation

With the proviso that ‘nobody in Copenhagen (or anywhere else) ever set down in so many words a definitive statement labelled “the Copenhagen interpretation”’, the earliest interpretation of quantum physics is named after Niels Bohr’s Institute of Physics in Copenhagen.⁵⁴ His institute was visited by nearly all of the greatest minds working on quantum physics in the 1920s, including Werner Heisenberg and Erwin Schrödinger.⁵⁵ According to Feynman, it was not until 1926-7 that quantum physics as we know it was developed, when Heisenberg and Schrödinger provided two explanations for interactions at the quantum level which clarified the field immensely.⁵⁶ Schrödinger published the wave equation that is now named after him in the 1926 paper ‘Quantisierung als Eigenwertproblem’.⁵⁷ A year later, Heisenberg confirmed that absolutely precise measurements in two mathematically connected properties are impossible at the quantum level.⁵⁸ The principle that in English is labelled the ‘uncertainty principle’

Snapshot of Foundational Attitudes toward Quantum Mechanics’, *Studies in History and Philosophy of Science Part B: Studies in History and Philosophy of Modern Physics* 44, no. 3 (2013): 222–230; Sujeevan Sivasundaram and Kristian Hvidtfelt Nielsen, ‘Surveying the Attitudes of Physicists Concerning Foundational Issues of Quantum Mechanics’, *ArXiv Preprint*, 2016, <https://arxiv.org/abs/1612.00676>.

⁵⁴ John Gribbin, *In Search of Schrödinger’s Cat* (1984; repr., London: Random House, 2012), 162–63.

⁵⁵ Kragh lists 63 visiting physicists from 1921 to 1930. Helge Kragh, *Quantum Generations: A History of Physics in the Twentieth Century* (Princeton, NJ: Princeton University Press, 1999), 160.

⁵⁶ Richard P. Feynman, *QED: The Strange Theory of Light and Matter*. (1985; repr., Harmondsworth: Penguin, 1990), 5.

⁵⁷ Erwin Schrödinger, ‘Quantisierung als Eigenwertproblem (Quantization as an Eigenvalue Problem)’, *Annalen der Physik* 384, no. 4 (1 January 1926): 361–76, <https://doi.org/10.1002/andp.19263840404>.

⁵⁸ To speak in precise mathematical terms, absolutely precise measurements are impossible in two non-commuting observables. Werner Heisenberg, ‘Über den anschaulichen Inhalt der quantentheoretischen Kinematik und Mechanik (On the Perceptual Content of Quantum Theoretical Kinematics and Mechanics)’, *Zeitschrift für Physik* 43, no. 3–4 (1 March 1927): 172–98, <https://doi.org/10.1007/BF01397280>.

is widely known in popular culture, although not always fully understood. The name of this concept, however, has led to misunderstanding, as it is based on a mistranslation. Heisenberg himself originally spoke of ‘Ungenauigkeit’, which translates to ‘inaccuracy’ or ‘inexactness’.⁵⁹ The term was originally translated both as ‘uncertainty’ and ‘indeterminacy’, with the former winning out in 1930, when the translators of Heisenberg’s monographs chose to use this term.⁶⁰ The crucial difference between the terms ‘uncertainty’ and ‘indeterminacy’ lies in the connotations the former term has for non-experts in particular: those of vagueness, lack of clarity, and doubt. These connotations have influenced the manner in which popularizers communicate quantum physics, because they have to counter the assumptions that arise from the connotations.

Schrödinger’s later contribution to quantum physics has gained much wider popular recognition, and has entrenched itself firmly in the public consciousness. In 1935, Schrödinger published the paper ‘Die gegenwärtige Situation in der Quantenmechanik’, in which he deliberately extrapolated Heisenberg’s uncertainty principle to the point of ridicule by applying it to a situation in which a cat is in a superposition of being dead and alive until an observation collapses its wavefunction.⁶¹ This thought experiment, with its morbid implications, was enthusiastically taken up in popular culture, making cats a stock element of popular expositions of quantum physics. Chapter 1 traces the usage of Schrödinger’s cat in contemporary popularizations. Fictional extrapolations of the cat paradox, involving humans being potentially

⁵⁹ Heisenberg, p. 172.

⁶⁰ David C. Cassidy, ‘Answer to Question #62. When Did the Indeterminacy Principle Become the Uncertainty Principle?’, *American Journal of Physics* 66, no. 4 (1 April 1998): 278–79, <https://doi.org/10.1119/1.18872>.

⁶¹ Erwin Schrödinger, ‘Die gegenwärtige Situation in der Quantenmechanik (The Present Situation in Quantum Mechanics)’, *Die Naturwissenschaften* 23, no. 48 (29 November 1935): 52, 808–12.

dead and alive at the same time, appear in several works discussed in the thesis, such as Greg Egan's *Quarantine* (1992) and David Walton's *Superposition* (2015).

The contested nature of the field first became visible to the general public in 1932, when Werner Heisenberg alone was awarded that year's Nobel Prize for Physics 'for the creation of quantum mechanics'.⁶² Schrödinger was awarded the Nobel Prize the next year, together with Paul A. M. Dirac, 'for the discovery of new productive forms of atomic theory'.⁶³ Schrödinger and Heisenberg are now considered to have contributed equally to the development of the Copenhagen interpretation, which in the mid-twentieth century became contested by several new interpretations. Contemporary physics students, however, are generally taught the Copenhagen interpretation, as I will explore further in Chapter 1.

The Conscious Collapse Interpretation

Physicists rarely support the conscious collapse, or Von Neumann-Wigner, interpretation, and treat it as fiercely controversial in their popularizations. In 1955, John von Neumann claimed in *Mathematical Foundations of Quantum Mechanics* that, since an external observer that is not part of the mathematical system is necessary to collapse the wavefunction, the observer has to be a conscious being.⁶⁴ Eugene Wigner expressed

⁶² Nobel Media AB 2014, 'The Nobel Prize in Physics 1932', *Nobelprize.Org* (blog), accessed 10 February 2015, http://www.nobelprize.org/nobel_prizes/physics/laureates/1932/index.html.

⁶³ Nobel Media AB 2014, 'The Nobel Prize in Physics 1933', *Nobelprize.Org* (blog), accessed 19 February 2015, http://www.nobelprize.org/nobel_prizes/physics/laureates/1933/.

⁶⁴ John von Neumann, *Mathematical Foundations of Quantum Mechanics* (1955; repr., Chichester: Princeton University Press, 1996).

a similar view in a 1961 paper, arguing that ‘the quantum description of objects is influenced by impressions entering my consciousness.’⁶⁵ Although it is difficult to define what constitutes consciousness – can Schrödinger’s cat collapse its own wave function? – the conscious collapse interpretation paved the way for an interpretation of physics in which humankind has a special and preferred role. This subjective preference for an interpretation in which humanity is central has long been an influential factor in scientific theorization, as can be seen in the conflict between the heliocentric and the geocentric models of the solar system.

In a select group of popularizations, however, the conscious collapse interpretation has been embraced with much enthusiasm, as it restores human consciousness and human agency to a central place in the universe, lending support to those who believe in a soul or spirit. Mystical misinterpretations of conscious collapse have been particularly numerous. These pseudoscientific works have been influential to the extent that some physicists consider them dangerous; I will discuss these authors’ responses to misinterpretations of quantum physics in Chapter 1. Pseudoscientific interpretations themselves are not discussed in the thesis. They extend quantum physics in a way no physicist would recognize, and do not engage in the debates regarding the various interpretations.

Nevertheless, some fiction that does not carry any religious or spiritual connotations does make use of the conscious collapse interpretation. Chapter 6 addresses Greg Egan’s *Quarantine*, which employs this interpretation to allow a character to control wavefunction collapse, although Egan has stated in a blog that he does not believe

⁶⁵ Eugene P. Wigner, ‘Remarks on the Mind-Body Question’, in *Symmetries and Reflections* (1961; repr., Bloomington: Indiana UP, 1967), 171–84, p. 173.

this interpretation to be true.⁶⁶ The narrative possibilities of this interpretation have made it popular among fiction authors, while few scientists support it.

The Many-Worlds Interpretation

The interpretation of quantum physics that has become most famous in popular culture, now known as the many-worlds or Everett interpretation, was proposed in 1957. In the article “‘Relative State’ Formulation of Quantum Mechanics’, based on his PhD thesis, Hugh Everett III argued that the wavefunction does not collapse: all of the possibilities encoded in it do happen.⁶⁷ An observation reveals one of these realities, but all other probabilities also exist, in worlds parallel to our own but inaccessible to us. This interpretation removes the need for the observer to be conscious. The theory was largely ignored until the late 1960s, when Everett’s supervisor, John Wheeler, began to express his support for his pupil’s theory; the interpretation is therefore also known as EWG, or Everett-Wheeler-Graham.⁶⁸ Wheeler himself had until then been developing a further version of the conscious collapse interpretation.

As I will show in Chapters 1 and 6, the many-worlds interpretation is not commonly adhered to by physicists, the University of Oxford being one major exception, yet nearly all popular physics books favour it.⁶⁹ The concept of parallel worlds that are

⁶⁶ Greg Egan, ‘Quantum Mechanics and Quarantine’, 18 January 2008, <http://www.gregegan.net/QUARANTINE/QM/QM.html>.

⁶⁷ Hugh Everett III, “‘Relative State’ Formulation of Quantum Mechanics’, *Reviews of Modern Physics* 29, no. 3 (1957): 454–62; Hugh Everett III, ‘On the Foundations of Quantum Mechanics’ (Princeton University, 1957), <https://search.proquest.com/docview/301919284>.

⁶⁸ Bryce S. DeWitt, ‘Quantum Mechanics and Reality’, *Physics Today* 23, no. 9 (September 1970): 30–35, <https://doi.org/10.1063/1.3022331>.

⁶⁹ For exceptions coming out of the Oxford system, see, for instance, the influential work by David Deutsch in quantum computing and David Wallace in philosophy of physics. David Deutsch, *The Fabric of Reality* (1997; repr., London: Penguin, 1998); David Wallace, *The Emergent Multiverse: Quantum Theory According to the Everett Interpretation* (Oxford: Oxford University Press, 2012).

just a little bit different from ours, which are inaccessible to us at present but seemingly all around us, resonates with long-existing narratives of alternate histories and inter-world travelling.⁷⁰ Whereas fiction authors' preference for Everett is partly due to this narrative compatibility, the interpretation's presence in a large number of popular science books is also part of a larger conflict narrative.

The disagreement between experts regarding scientific interpretation has in some cases become personal. Authors have made use of the opportunity to gain support for the theory they favour by communicating their findings to a wide audience in a partisan manner. Personal conflicts are particularly visible in popular astrophysics books by scientists; the rapid development of this field in the twentieth century gave rise to several conflicting interpretations of the origin of the universe and black holes. To communicate quantum physics, authors such as John Gribbin, Chad Orzel and Alastair I. M. Rae resorted to selective popularization, focusing on those topics that would render the most captivating story. Scientific conflict, which tends to be omitted from university teaching on the subject, is thus explicitly present in popularizations, making it clear to the reader that quantum physics is in a constant state of flux. My first two chapters focus on different forms of what I call conflict narratives, popular works that negotiate a conflict among scientists. These works do not only intend to explain science; they are also written to convince the reader to take a side in the conflict. I investigate how such conflict narratives influence the reader's idea of what quantum physics is, and how these narratives shape science itself through popularization.

⁷⁰ Ryan, 'From Parallel Universes to Possible Worlds'.

The thesis confines itself to one field within physics. The narrow topic selection allows for an in-depth consideration of a wide range of material, covering four interlocking modes of writing for children and adults, fiction and nonfiction, over a historical period of more than a century. The research undertaken has revealed parallels between the approaches to quantum physics in works of fiction and nonfiction that have not been addressed before, shedding new light both on the structure of popular science works and on the mutual influences between quantum physics and the stories written about it.

Structure

The chapters of the thesis are arranged thematically, each focusing on a different narrative form. The first chapter investigates the content and structure of quantum physics textbooks and book-length quantum physics popularizations, focusing on the period from 1957 onwards, when several interpretations of quantum physics had begun to compete for prestige and fame. It considers how, and how quickly, new ideas were first introduced to a non-physicist audience, and how these ideas were adapted selectively to emphasize those elements that would make the most compelling story. The section takes as a case study the works of physicist Alastair I.M. Rae, who wrote both university textbooks and popular accounts of quantum physics, in order to compare the communication of the Copenhagen interpretation to both physicists and non-physicists.

The second chapter focuses on what I call the conflict narrative: a popular science narrative that offers a partisan account of conflicting interpretations in physics. Many of the less testable theories within quantum physics are subject to disagreement

and controversy. Since most popularizations are single-authored, the views of a single scientist can have major ramifications for the perception of their field in the public imagination. When quantum physics began to influence cosmology, two conflicts arose in the public sphere, which form the case studies in this chapter. Fred Hoyle and George Gamow conflicted on the steady state theory versus the big bang, and Stephen Hawking clashed with Leonard Susskind on the black hole information paradox.⁷¹ This chapter investigates these physicists' approaches to making their conflicts public, and discusses how science can no longer be presented exclusively as objective in a discourse in which authors have to convince their audience of the legitimacy of their scientific theories.

As mentioned above, the usefulness and appropriateness of metaphor and analogy in science writing has been the subject of much debate. Little attention, however, has been given to popular science books that use a fantasy narrative as the source for the entire set of metaphors used to explain the scientific content, a form which Gamow called a 'scientifically fantastic story.'⁷² Chapter 3 takes as its case studies three such works for adults, each from a different century: Edwin A. Abbott's *Flatland* (1884), George Gamow's *Mr Tompkins* (1939-1965) and Robert Gilmore's *Alice in Quantumland* (1995).⁷³ This chapter investigates the implications of explaining science in a fantasy

⁷¹ Fred Hoyle, *The Nature of the Universe: A Series of Broadcast Lectures* (Oxford: Basil Blackwell, 1950); George Gamow, *Mr Tompkins in Paperback* (1965; repr., Cambridge: Cambridge University Press, 1993); Stephen Hawking, *A Brief History of Time: From the Big Bang to Black Holes* (London: Bantam Books, 1988); Leonard Susskind, *The Black Hole War: My Battle with Stephen Hawking to Make the World Safe for Quantum Mechanics* (New York: Back Bay Books, 2009).

⁷² George Gamow, *Mr Tompkins in Wonderland, or Stories of c , G , and h* (Cambridge: Cambridge University Press, 1939), xi.

⁷³ Edwin Abbott Abbott, *Flatland: A Romance of Many Dimensions* (London: Seeley & Co., 1884); Gamow, *Mr Tompkins in Wonderland*; George Gamow, *Mr Tompkins Explores the Atom* (Cambridge: Cambridge University Press, 1946); Robert Gilmore, *Alice in Quantumland: An Allegory of Quantum Physics* (New York: Copernicus, 1995).

narrative, paying particular attention to the clash between the speculative nature of the overarching story and the alleged objectivity of the scientific content.

Chapter 4 applies the concept of the ‘scientifically fantastic story’ to quantum physics books for children. Three relatively recent works explain this field to a young readership: Russell Stannard’s *Uncle Albert and the Quantum Quest* (1994), Lucy and Stephen Hawking’s *George* series (2009-2016), and Otto Fong’s *The Quantum Bunny* (2015).⁷⁴ Melanie Keene discussed the use of fantasy elements, in particular elements from *Alice’s Adventures in Wonderland* (1865), in nineteenth-century science writing for children which presented science as stranger and more amazing than fiction.⁷⁵ I will ask why these elements, including Alice, continue to be present in contemporary children’s science books, and what effect the use of these elements has on the readers’ understanding of, and engagement with, quantum physics.

In Chapter 5, I shed new light on two famous children’s book series through an evaluation of their scientific contents. Madeleine L’Engle’s *Wrinkle in Time* quintet (1962-1989) and Philip Pullman’s *His Dark Materials* trilogy (1995-2000) are most often critically approached in terms of their approaches to religion.⁷⁶ Whereas L’Engle’s works endorse a Christian view, Pullman’s series attacks institutionalized Christianity. However, the approach to science that both works take is surprisingly similar. Both

⁷⁴ Russell Stannard, *Uncle Albert and the Quantum Quest* (London: Faber and Faber, 1994); Lucy Hawking and Stephen Hawking, *George’s Secret Key to the Universe* (London: Ted Smart, 2007); Otto Fong, *The Quantum Bunny*, *Sir Fong’s Adventures in Science 5* (Singapore: Ottonium Comics, 2015).

⁷⁵ Keene, *Science in Wonderland*.

⁷⁶ Madeleine L’Engle, *A Wrinkle in Time* (1962; repr., New York: Square Fish, 2007); Madeleine L’Engle, *A Wind in the Door* (1973; repr., New York: Square Fish, 2007); Madeleine L’Engle, *A Swiftly Tilting Planet* (1978; repr., New York: Square Fish, 2007); Madeleine L’Engle, *Many Waters* (1986; repr., New York: Square Fish, 2007); Madeleine L’Engle, *An Acceptable Time* (1989; repr., New York: Square Fish, 2007); Philip Pullman, *Northern Lights* (1995; repr., London: Scholastic, 2007); Philip Pullman, *The Subtle Knife* (1997; repr., London: Scholastic, 2007); Philip Pullman, *The Amber Spyglass* (2000; repr., London: Scholastic, 2007).

series present a world that is for the largest part clearly fantastical, in which religion is central, and which is made more believable through its foundation in modern physics. I argue that the scientific content of these series strongly influences both the narrative structure of the texts and the authors' arguments about religion.

The final chapter looks at quantum physics in fiction for adults, covering the twentieth and twenty-first centuries. Once the author decides to use quantum physics in fiction, they are faced with several conflicting interpretations of the theory. I investigate the narrative consequences of opting to use a particular interpretation, as it shapes and limits the form the narrative can take. The Copenhagen interpretation in David Walton's *Superposition* duology (2015) enables characters to be dead and alive at the same time; Greg Egan's *Quarantine* (1992) applies the conscious collapse interpretation, which suggests the possibility of avoiding death. The many-worlds interpretation allows for branching universes and travel between them; in Iain Pears's *Arcadia* (2015) this branching has been applied to both the narrative and the structure of the app-novel. This last work opens up a wider conjecture: in the digital age, when new media forms such as hyperfiction can more closely approximate the fabric of the universe according to various interpretations, the future might bring stories of quantum physics that both the original scientists and storytellers may have thought unimaginable.

Together, the case studies show that the stories of quantum physics cut across the traditional and institutionalized boundaries of fiction and nonfiction, science fiction and fantasy, and children's and adult literature. The thesis argues that these stories make use of a shared set of tropes and devices that includes conflict narratives, the explicit articulation of the limits of scientific knowledge, and, as my first chapter will show, quite a few cats.

Chapter One: Selective Popularization

Framing the Narratives of Popular Quantum Physics Books

'In fact, the mere act of opening the box will determine the state of the cat, although in this case there were three determinate states the cat could be in: these being Alive, Dead, and Bloody Furious.'
- Terry Pratchett¹

Introduction

Erwin Schrödinger is famous for two things: his equations and his cat. His equations, published in 1926, enabled the mathematical prediction of the change of a quantum system over time, and are included in all textbooks on quantum physics.² Nearly a decade later, in 1935, Schrödinger outlined his now famous cat paradox to emphasize some of the conceptual problems which the Copenhagen interpretation was ill-equipped to handle.³ Unlike textbooks, popularizations usually give priority to Schrödinger's cat, a concept with which the reader is usually assumed to be familiar, even if they do not understand precisely what it means, as I will show in the three case studies of this chapter, Alastair I.M. Rae's *Quantum Physics: illusion or reality?* (1986), *Quantum Physics: A Beginner's Guide* (2008) and the textbook *Quantum Mechanics* (2008).⁴ A full history tracing the adoption of Schrödinger's cat in popular culture is yet to be written; the cat is absent from George Gamow's quantum physics popularizations (1939-

¹ Terry Pratchett, *Lords and Ladies* (London: Corgi Books, 1993), 199.

² Schrödinger, 'Quantisierung als Eigenwertproblem (Quantization as an Eigenvalue Problem)'.

³ Schrödinger, 'Die gegenwärtige Situation in der Quantenmechanik (The Present Situation in Quantum Mechanics)'.

⁴ Rae, *Illusion or Reality?*, 1986; Alastair I. M. Rae, *Quantum Physics: A Beginner's Guide* (2005; repr., London: Oneworld, 2014); Alastair I. M. Rae and Jim Napolitano, *Quantum Mechanics*, 1980. Sixth ed. (Boca Raton, FL: CRC Press, 2016).

1966),⁵ which suggests that the cat paradox took several decades to permeate popular culture.

The thought experiment was written in a manner that facilitated adoption in popular culture: it is a standalone narrative that does not include equations and is comprehensible to a non-expert reader. The following paragraph is Schrödinger's full description of his famous thought experiment:

One can even set up quite ridiculous cases. A cat is penned up in a steel chamber, along with the following device (which must be secured against direct interference by the cat): in a Geiger counter there is a tiny bit of radioactive substance, *so small*, that *perhaps* in the course of the hour one of the atoms decays, but also, with equal probability, perhaps none; if it happens, the counter tube discharges and through a relay releases a hammer which shatters a small flask of hydrocyanic acid. If one has left this entire system to itself for an hour, one would say that the cat still lives *if* meanwhile no atom has decayed. The psi-function of the entire system would express this by having in it the living and dead cat (pardon the expression) mixed or smeared out in equal parts.⁶

Marie-Laure Ryan, in an article that discusses the relations between quantum physics and narrative, explores the narrative possibilities that the cat paradox has engendered. She claims that Schrödinger's description did not have much of a narrative to it: 'The only attempt to create an emotional response is the suggestion that the killing device is diabolical, a detail that induces pity for the cat. The story does not satisfy the audience's desire to find out how it ends, since it focuses on an unresolved possibility.'⁷ The term 'diabolical' she refers to is taken from a letter Schrödinger wrote to Einstein,

⁵ Gamow, *Mr Tompkins in Wonderland*; Gamow, *Mr Tompkins Explores the Atom*; Gamow, *Mr Tompkins in Paperback*; George Gamow, *Thirty Years That Shook Physics: The Story of Quantum Theory* (1966; repr., New York: Dover Publications, 1985).

⁶ John D. Trimmer, 'The Present Situation in Quantum Mechanics: A Translation of Schrödinger's "Cat Paradox" Paper', *Proceedings of the American Philosophical Society* 124, no. 5 (10 October 1980): 323–38, <https://doi.org/10.2307/986572>, p. 328. Italics in original.

⁷ Ryan, 'Narrative/Science Entanglements', p. 177.

dated 19 August 1935, in which he first sketched out the cat paradox.⁸ Ryan seems to underestimate the emotional impact of the threat to the cat's life. Popular works use this impact as a way to engage the reader: the paradox is often alluded to, but not explained, throughout the first half of the popularization, as a teaser to maintain the reader's interest. The reader is familiar with the more sensational parts of the story – the attraction of something being alive and dead at the same time, but also the idea of a beloved animal dying – but they need to wait patiently for the science behind these unsettling ideas.

Textbooks, meanwhile, dismiss the cat paradox, either omitting it entirely or relegating it to a final chapter that is not intended to be required reading. Velentzas et al., in a 2007 study, compared the use of thought experiments to explain special relativity, general relativity, and quantum mechanics in textbooks and popular science books.⁹ They observed that popular books make use of thought experiments slightly more often than textbooks: 86% of the popular books and 80% of the textbooks they investigated made use of thought experiments to present the uncertainty principle.¹⁰ There are some problems with their methodology: for instance, to define their popular science sample, the authors used the criterion that ‘The most complex mathematical formula used is that of the Pythagorean Theorem’, yet they included Albert Einstein's *Relativity*, which contains a derivation of the Lorentz transformation. Although they did not define the term ‘formula’, they used it elsewhere in reference to $E=mc^2$ and ‘the

⁸ The letter is quoted in Baggott, *The Quantum Story*, 154, where Baggott compares this original description to the eventually published version of the cat paradox.

⁹ Athanasios Velentzas, Krystallia Halkia, and Constantine Skordoulis, ‘Thought Experiments in the Theory of Relativity and in Quantum Mechanics: Their Presence in Textbooks and in Popular Science Books’, *Science & Education* 16 (27 February 2007): 353–70, <https://doi.org/10.1007/s11191-006-9030-1>.

¹⁰ Velentzas, Halkia, and Skordoulis, 362.

formula of the dilation of time',¹¹ a formula which incorporates the Lorentz transformation, so their haphazard use of the term 'formula' seems to be a methodological error rather than a definition issue. Their range of primary texts is problematic too: they classified their sample of popular books as 'addressed to the public or to junior high school students' yet it ranges from Hawking's *A Brief History of Time* to two of Russell Stannard's children's books about Uncle Albert.¹² Nevertheless, their paper noted that 'the [thought experiment] "Schrödinger's cat" is not reported in [textbooks] in contrast to the [*sic*] "Heisenberg's microscope"'.¹³ A saturation with cat imagery on the part of both author and reader may have influenced the decision to exclude the cat. In this chapter, I will not only evaluate whether a certain concept is present in or absent from a popular work; I will also delve into the language that is used in explaining such concepts, and the way in which the work as a whole frames them.

This chapter will investigate how structuring a compelling narrative leads to selecting those parts of quantum physics that lend themselves most easily to narrativization. If textbooks and popularizations construct different narratives about Schrödinger's contribution to quantum physics, physicists and non-experts will gain different understandings of the field and the questions it asks. When writing a book about quantum physics, authors have to decide which topics to address, how much space to dedicate to each, and how to connect the topics: chronologically in order of discovery, or starting with the topic that is easiest to understand. The authors' selections are based on their own personal preferences and professional opinions, their assumptions

¹¹ Velentzas, Halkia, and Skordoulis, 362–63.

¹² Velentzas, Halkia, and Skordoulis, 360, 364.

¹³ Velentzas, Halkia, and Skordoulis, 363. Heisenberg's microscope is a thought experiment that aims to prove Heisenberg's uncertainty principle by means of the laws of optics. Werner Heisenberg, 'The Uncertainty Principle (1929)', in *The World of Mathematics*, ed. James R. Newman, vol. 2 (1956; repr., London: George Allen & Unwin Ltd., 2000), 1051–1055.

about the intended audience, and their ideas about what their readership should learn. The nature of quantum physics as a theoretical field with many conflicting interpretations amplifies the effects of content selection on the public perception of the field, more so than in any other science. This chapter will explore how content selection influences the popular communication of quantum physics, focusing on the use of non-mathematical language as a bridging method to convey high physical theory. I will investigate how the topics that are commonly addressed in popularizations are presented in university-level physics textbooks, in order to see how scientific knowledge is constructed differently for physicists and non-physicists.

In *Research and Pedagogy* (2013), Massimiliano Badino and Jaume Navarro looked at quantum physics textbooks up to 1930; these works reflect change and conflict as well as consensus.¹⁴ Badino and Navarro show that the earliest textbooks on quantum physics, produced when even the Copenhagen interpretation was still being formulated, are not mere repositories of Kuhnian ‘normal science’. Textbooks are not only ‘*products* of scientific change, useful only as tools in training regimes, but also [...] *active agents* in the creative process of scientific development.’¹⁵ Bearing in mind this active role, I analyse only post-1960 textbooks and popularizations here; the time frame allows me to take into account whether the authors decide to include Schrödinger’s cat, the many-worlds interpretation, and the conscious collapse interpretation.

¹⁴ Massimiliano Badino and Jaume Navarro, eds., *Research and Pedagogy: A History of Quantum Physics through Its Textbooks* (Berlin: Edition Open Access, 2013), <http://edition-open-access.de/studies/2/>.

¹⁵ Massimiliano Badino and Jaume Navarro, ‘Pedagogy and Research. Notes for a Historical Epistemology of Science Education’, in *Research and Pedagogy: A History of Quantum Physics through Its Textbooks*, ed. Massimiliano Badino and Jaume Navarro (Berlin: Edition Open Access, 2013), 3–34, <http://edition-open-access.de/studies/2/>, p. 10.

The main case study of this chapter is the physicist and popularizer Alistair I.M. Rae. His two quantum physics popularizations, *Quantum Physics: Illusion or Reality?* (1986), and *Quantum Physics: A Beginner's Guide* (2005), are easily confused with each other: both the second edition of *Illusion or Reality?* and *A Beginner's Guide* simply bear the title *Quantum Physics* on their covers.¹⁶ The two books actually complement each other: whereas *Illusion or Reality?* mainly explained the conceptual basis of quantum physics, *A Beginner's Guide* focuses on practical applications. Rae is also the author of the textbook *Quantum Mechanics* (1980, 6th ed. with Jim Napolitano 2016). As he is one of the very few authors who has written both a textbook and popular books, his works facilitate a comparison between these two genres without other variables coming into play.

This chapter also covers a peculiar subgenre: that of semipopular texts, which are intended to bring the amateur reader's knowledge up to the level needed to study quantum physics in university, and which therefore include advanced mathematics. As examples of this genre, I will discuss David McMahon's *Quantum Mechanics Demystified* (2006) and Leonard Susskind and Art Friedman's *Quantum Mechanics: The Theoretical Minimum* (2014).¹⁷ The works discussed in this chapter are chosen for their exclusive focus on quantum physics. Textbooks such as Kenneth Krane's *Modern Physics*, which devotes a third of its contents to quantum physics, and popularizations such as Stephen

¹⁶ Rae, *Illusion or Reality?*, 1986; Alastair I. M. Rae, *Quantum Physics: Illusion or Reality?*, 2nd ed. (Cambridge: Cambridge University Press, 2004); Rae, *A Beginner's Guide*.

¹⁷ David McMahon, *Quantum Mechanics Demystified*, 2006. 2nd ed. (New York: McGraw-Hill Education, 2013); Leonard Susskind and Art Friedman, *Quantum Mechanics: The Theoretical Minimum* (2014; repr., London: Penguin Books, 2015). Other quantum physics books in this genre include Steven Holzner, *Quantum Physics for Dummies* (Hoboken, NJ: Wiley, 2009) and Alexandre Zagoskin, *Quantum Mechanics: A Complete Introduction* (London: John Murray Learning, 2015).

Hawking's *A Brief History of Time*, which devotes only one of its eleven chapters to explaining quantum physics, are therefore not included.¹⁸

The final section of this chapter addresses the fraught relationship between quantum physics, philosophy, and New Age spirituality. New Age works that make use of quantum physics concepts are rarely written by authors with a physics background, and the concepts covered in them are frequently misinterpreted or incorrectly explained, which has led to a wholesale rejection of spirituality and philosophy in most popular works by physicists.

Authors of both textbooks and popularizations rely on narrative techniques to keep their audience engaged and to facilitate the introduction of challenging concepts. One might consider it unlikely for a textbook to contain a narrative; however, the author can create a sense of coherence by carefully ordering the concepts, which urges the reader to progress through the book. Textbooks tend to present their contents in such a way that later chapters build on the mathematical skills acquired in the previous chapters; popular works either organize their narrative chronologically, or make use of a protagonist who learns. As explored further in Chapter 3, having a fictional protagonist encounter the different concepts taught in the book facilitates narrative coherence as the ignorant protagonist slowly becomes more knowledgeable and is able to make connections between encounters with different phenomena. If the author does not make use of a fictional setting, human protagonists still play an important role: the history of quantum physics tends to be told through its key scientists, such as Schrödinger, Heisenberg, and Einstein. Referring to human protagonists – or animal ones,

¹⁸ Kenneth S. Krane, *Modern Physics*, 1983. 2nd ed. (New York: Wiley, 1996); Hawking, *A Brief History of Time*.

such as Schrödinger's cat and Chad Orzel's dog¹⁹ – gives the reader an anchor at their own scale in between moments where they are asked to stretch their imagination to improbably small or large scales. The topics that are more easily woven into appealing narratives with human or animal protagonists are more likely to be included in popularizations. I will focus on three quantum physics topics and the ways in which popularizers include or omit them: Schrödinger's cat and equations, the Copenhagen and many-worlds interpretations, and philosophy and mysticism, starting with an analysis of semipopular texts.

Semipopular Texts

Works such as Leonard Susskind and Art Friedman's *Quantum Mechanics: The Theoretical Minimum* and David McMahon's *Quantum Mechanics Demystified* problematize the idea of the popular science book as written for a 'general' audience. Susskind's work is the sequel to his *The Theoretical Minimum: What You Need to Know to Start Doing Physics* (2013);²⁰ both are sold as mass-market paperbacks, published in the UK by Penguin. However, they are intended to introduce readers to physics at university level – classical mechanics in the first book, quantum mechanics in the second – and to be complemented by the freely available online lectures Susskind gave as part of the Stanford Continuing Studies programme.²¹ *Quantum Mechanics Demystified* is a self-study book, designed to reach the same level. Unlike regular popular science books, Susskind and McMahon therefore require the reader to have a strong mathematics background:

¹⁹ Chad Orzel, *How to Teach Quantum Physics to Your Dog* (Oxford: Oneworld, 2010).

²⁰ Leonard Susskind and George Hrabovsky, *The Theoretical Minimum: What You Need to Know to Start Doing Physics* (London: Allen Lane, 2013).

²¹ 'About', The Theoretical Minimum, 2012, <http://theoreticalminimum.com/about>.

McMahon lists ‘calculus, how to solve ordinary and partial differential equations, [...] matrices/linear algebra and at least a basic working knowledge of complex numbers and vectors’ as his prerequisites; Susskind and Friedman are less demanding and ask for ‘some basic knowledge of calculus and linear algebra,’ as well as a grasp of the material covered in the previous volume.²² This mathematical rigour makes the works ‘semipopular’ texts, according to Robert T. Kelley’s definition:

[The semipopular text] seeks to be true to the science it is portraying (not simplifying it overmuch) but does skip some of the mathematical development and experimental data that would be expected in a more traditional scientific paper. It makes assertions about a science and about its implications without rigorous proof and is therefore close in form to the scientific textbook; it teaches all that is necessary and gives enough information to make that knowledge useful.²³

Notably, this is a different kind of in-between genre from the one Martin Eger proposes in the same volume, ‘the new epic of science’, which he refers to as ‘the third genre of science literature’.²⁴ Eger speaks of ‘mostly full-length books combining high-quality writing with scientific depth’, contrasting this to popularizations, which he considers to be ‘the usual simplified expositions that do not claim to convey a serious message’.²⁵ He emphasizes the literary quality of the writing in these texts, including in his selection such disparate works as Steven Weinberg’s *The First Three Minutes* (1977) and Douglas Hofstadter’s *Gödel, Escher, Bach* (1979).²⁶ This literary quality is not a charac-

²² Susskind and Friedman, *Quantum Mechanics*, 2015, xvi; McMahon, *Quantum Mechanics Demystified*, xiv.

²³ Robert T. Kelley, ‘Chaos out of Order: The Writerly Discourse of Semipopular Scientific Texts’, in *The Literature of Science: Perspectives on Popular Scientific Writing*, ed. Murdo William McRae (Athens, GA: University of Georgia Press, 1993), 132–51, p. 148, note 1.

²⁴ Martin Eger, ‘Hermeneutics and the New Epic of Science’, in *The Literature of Science: Perspectives on Popular Scientific Writing*, ed. Murdo William McRae (Athens, GA: University of Georgia Press, 1993), 186–209, p. 192.

²⁵ Eger, pp. 186–7.

²⁶ Steven Weinberg, *The First Three Minutes: A Modern View of the Origin of the Universe* (1977; repr., London: Deutsch, 1978); Douglas R. Hofstadter, *Gödel, Escher, Bach* (Hassocks: Harvester Press, 1979).

teristic of the semipopular texts I discuss here; Weinberg's and Hofstadter's works require the advanced critical thinking skills university graduates are trained in, but they do not contain university-level mathematics. Eger's definition of a popularization is rather blunt and, depending on one's definition of 'a serious message', does not do justice to many of the works discussed in this chapter. Works that convey a serious message in Eger's sense 'distill the deeper meaning of scientific advances on fairly broad fronts, calling attention to cognitive implications that bear on human self-understanding.'²⁷ I do not wish to claim that popularizations that do not 'bear on human self-understanding' do not convey a serious message: the understanding of the science can in itself be such a message. However, Eger's point about the cognitive implications certainly rings true: below, I will further discuss the fact that these often remain absent from regular quantum physics popularizations.

The most important difference between semipopular texts and textbooks is the intended audience: the purpose of a textbook is 'the transmission of knowledge from the scientific elite to those who are supposed to replace it in the near future.'²⁸ Textbooks are written for students of whom it is assumed they will continue applying the gained knowledge in further courses, and in their later careers. Semipopular texts, on the other hand, are intended to reach an audience beyond the university physics department, including people who already have different careers and will never become physicists. As Art Friedman, who was one of Susskind's Continuing Studies students, writes in the introduction to *Quantum Mechanics: The Theoretical Minimum*,

the world seems filled with people who are genuinely, deeply interested in physics but whose lives have taken them in different directions. This book is for

²⁷ Eger, 'Hermeneutics and the New Epic of Science', 187.

²⁸ Badino and Navarro, 'Pedagogy and Research', p. 8.

all of us. [...] We have tried to make this amazing body of work fully accessible to mathematically literate nonphysicists.²⁹

Friedman emphasizes that his ideal reader is someone with the intellectual potential to be a physicist, who has chosen a different career path. Similarly, McMahon writes that

it is our hope that the book will help ‘demystify’ quantum theory for those who are interested in self-study or for those from different backgrounds such as chemistry, computer science, or engineering, who would like to learn something about quantum mechanics.³⁰

Semipopular texts are more difficult to evaluate in literary terms than regular popularizations, because they have exercises in them; the reader is supposed to break up the flow of reading to work through them.

The way in which the *Theoretical Minimum* books are marketed merits closer attention. The vast majority of non-scientists working through these books would not gain any practically applicable skills. It is difficult to think of any non-science professions that would be enlightened by learning the mathematics behind quantum mechanics. Even so, *Quantum Mechanics: The Theoretical Minimum* is very explicitly sold using an instrumentalist rhetoric towards non-scientists. The blurb describes the book as ‘a practical toolkit for amateur scientists’. The cover of the Basic Books edition similarly suggests practical, tangible applications: it depicts screws, bolts, and what looks like Meccano.³¹ This marketing suggests that the reader will learn applicable skills they could use to participate meaningfully in the scientific world, which is not the case: the

²⁹ Susskind and Friedman, *Quantum Mechanics*, 2015, xiii.

³⁰ McMahon, *Quantum Mechanics Demystified*, xiv. The use of the first-person plural in a single-authored book can be considered an attempt to sound impersonal without having to resort to the artificiality of the passive voice.

³¹ Leonard Susskind and Art Friedman, *Quantum Mechanics: The Theoretical Minimum* (New York: Basic Books, 2014).

reader might be able to *understand*, but not *participate*. Nor will building up this mathematical capital help the reader become a better citizen scientist, as might have been the case in earlier centuries, especially in the field of astronomy; this rhetoric harks back to the very traditional language of the amateur scientist. The marketing obscures the fact that, especially in the twenty-first century, understanding and knowledge alone are not enough for someone to be considered a physicist; being part of the established social structure of academia is equally essential for making contributions to science. Using Charlotte Sleight's terms, one could say that the works are able to educate 'scientific outsiders', but not 'outsider scientists':

A scientific outsider does not attain to such a contribution, although there may sometimes be a subconscious underlying desire to do so, or even to be an insider. A scientific outsider may, for example, exist irrevocably within the wrong social circles, or may use methods unconscionable to the mainstream. Indeed, he or she may not wish to be part of insider science, or may attempt to challenge its nature. Nevertheless, he or she maintains an insistent engagement with science.³²

The marketing strategy suggests a conservatism that causes popular science publishers to adhere to a dated rhetoric that is no longer aligned with the publishing context of modern popularizations. Notably, this instrumentalist rhetoric is not used by Susskind or Friedman in their introductions: both emphasize understanding and participation motivated by interest and curiosity.

However, the way in which *The Theoretical Minimum* is framed and advertised can also be considered a response to modern developments in science communication, in which the relations between science and the public have undergone drastic revision. As discussed in the Introduction, the field has moved from a 'public understanding of

³² Charlotte Sleight, 'Writing the Scientific Self: Samuel Butler and Charles Hoy Fort', *Journal of Literature and Science* 8, no. 2 (2015): 17–35, p. 18.

science' (PUS) model to 'public engagement with science and technology' (PEST). These semipopular books attempt to present themselves as facilitating the transformation of the reader into an active participant in the scientific process. Susskind's co-author Art Friedman can be considered a perfect example of such a participant: he moves from being one of Susskind's students to being the co-author of the book that accompanies the course. However, for most readers there are no future applications, democratic or personal, of these quantum physics skills; moreover, whereas Susskind's original course was open to active participation, the book and video lectures do not allow such interaction.

Schrödinger, His Cat, and His Equations

Both in textbooks and in popular science books, Erwin Schrödinger is usually one of the first quantum physicists to be introduced. Textbooks and popularizations differ in the way they cover his aforementioned two contributions, both in the order in which they are presented and the amount of attention that is given to each. Whereas university textbooks usually take Schrödinger's equations as their starting point, works for a non-expert audience tend to gloss over these equations as being too difficult to explain to the reader, and base their explanation on the assumption that the reader has heard of Schrödinger's cat.

Gribbin refers to the cat in the prologue of *In Search of Schrödinger's Cat*, explaining the ideas underlying the paradox, but the quantum mechanical explanation does not appear until page 263, where a separate section on this paradox starts.³³ He

³³ Gribbin, *In Search of Schrödinger's Cat*, 18–19, 263–69.

uses the cat as a teaser to maintain the interest of the reader, as mentioned above: his section on the paradox has been preceded by suggestive mentions such as ‘But first, for completeness, we ought to look at some of the other paradoxical possibilities inherent to the quantum rules – particles that travel backward in time and, at last, Schrödinger’s famous half-dead cat.’³⁴ Of course, ‘half-dead’ is not a correct term for a cat in a superposition of dead and alive, and the point Schrödinger was making was that the story of his cat indicated not a possibility, but a ridiculous, impossible situation. As Egil Asprem aptly points out, ‘Schrödinger’s poor cat has gone from servicing a pedantic point about problems in the Copenhagen interpretation, to becoming a catchy emblem for “weird new science.”’³⁵ Asprem argues that associating Schrödinger’s cat with a weirdness that goes far beyond its original intention also means that the ‘concept tends to get classified and connected with other “weird things” — from telepathy and reincarnation to channeling, parallel universes, and mind-over-matter.’³⁶ I will discuss the implications of this association further below.

Chad Orzel similarly defers the explanation of the cat paradox. In *How to Teach Quantum Physics to Your Dog*, Orzel, a physicist, explains quantum physics to his dog Emmy, who speaks English.³⁷ The use of a dog protagonist in a quantum physics book opens up several possibilities for dog/cat jokes. Orzel introduces his book by stating that ‘Some elements of quantum theory have even escaped the realm of physics and

³⁴ Gribbin, 239.

³⁵ Egil Asprem, ‘How Schrödinger’s Cat Became a Zombie: On the Epidemiology of Science-Based Representations in Popular and Religious Contexts’, *Method & Theory in the Study of Religion* 28, no. 2 (11 May 2016): 113–40, <https://doi.org/10.1163/15700682-12341373>, p. 131.

³⁶ Asprem, 132.

³⁷ Orzel, *How to Teach Quantum Physics to Your Dog*. The reader is supposed to identify with this dog; by doing so, Orzel shows that he entertains certain cultural assumptions about his readership: in many cultures, such a comparison to a dog, who even seems to understand the topic better at times than the human reader, could be interpreted as insulting.

captured the popular imagination, like [...] Erwin Schrödinger's cat paradox'.³⁸ At the beginning of the third chapter, titled 'Schrödinger's Dog: The Copenhagen Interpretation', Emmy encounters the paradox for the first time. The paradox is here explained qualitatively and jokingly, emphasizing Emmy's approval of putting cats in boxes because she hates them; the full explanation – without mathematics – follows at the end of the chapter.³⁹ Orzel's double coverage of the paradox allows him to acknowledge the cat's position in popular culture while making sure that all readers fully understand the scientific content of the paradox.

Rae discusses the cat halfway through *Illusion or Reality*, but does not hint at it before that.⁴⁰ In *A Beginner's Guide*, on the other hand, he does not cover the cat until his final chapter, but he drops hints about the cat paradox throughout the book to keep the reader engaged, twice referring to 'Schrödinger's famous (or notorious) cat'.⁴¹

Gribbin, Orzel and Rae thus use the one aspect of quantum physics they expect most of their readers to be familiar with to maintain the reader's interest long enough to provide them with a more extensive explanation of the wider field of quantum physics. Not only is it necessary to teach the reader the principles of quantum physics before the cat paradox can be fully understood; the reader would also be more easily inclined to abandon the book at an early stage if the concept that drew them in initially is explained on the first pages.

Even though the authors assume some familiarity with Schrödinger's cat on the reader's part, it is notable that they never make this assumption explicit in the actual

³⁸ Orzel, 5.

³⁹ Orzel, 55–80.

⁴⁰ Rae, *Illusion or Reality?*, 1986, 59.

⁴¹ Rae, *A Beginner's Guide*, viii, 40.

explanation of the paradox. Gribbin calls the paradox ‘famous’, but explains it in full, never implying that this fame should mean that he expects the reader to actually understand what the paradox entails.⁴² He thus avoids the trouble of having to further pin down what exactly is ‘famous’ about the cat, which could very well amount to nothing more than the reader thinking of the word ‘cat’ when someone says ‘Schrödinger’. Including a teaser that suggests the reader will receive a full explanation of what the cat paradox entails can also assuage the fear a reader might have when seeing the word ‘famous’ and realising they do not know anything about Schrödinger’s cat.

Brian Cox and Jeff Forshaw, on the other hand, do seem to make this assumption about their readership: they refer to the cat in their introduction – ‘Cats can be both alive and dead’ – but they do not discuss the topic at all in their book.⁴³ Since they refer to the cat without naming or explaining the paradox, one may infer that they expect the reader to be already familiar with it. Although this might embarrass the reader who cannot actually remember the exact premise of the cat paradox, this approach fits the authors’ goals discussed below, of explaining only the many-worlds interpretation: using the cat to explain this interpretation would only work if the authors remove the cat from its historical context.

Although Schrödinger’s cat is presented as famous, various authors take some liberties in narrating a version of the paradox that is markedly different from Schrödinger’s official published version. The way in which the cat dies is a striking example. Schrödinger’s article mentioned the cat would be killed with ‘Blausäure’, hydrocyanic

⁴² Gribbin, *In Search of Schrödinger’s Cat*, 263.

⁴³ Brian Cox and Jeff Forshaw, *The Quantum Universe: Everything That Can Happen Does Happen* (London: Allen Lane, 2012), 4.

acid, whereas the letter exchange between him and Einstein put it much more dramatically: Einstein mentioned an ‘explosion’ resulting in ‘the pulverized cat’.⁴⁴ Rae mentions an entirely different way of killing in his various works: a ‘loaded revolver’ (1986); ‘a gun (or other lethal device)’ (2005); ‘fire a gun (or trigger some other lethal device)’ (2015).⁴⁵ Excitement, urgency, and a literal flash and bang are put back into the story where this was not present in the scientific paper: Rae makes the affective impact of the cat paradox even greater than Schrödinger’s original paragraph had made it.⁴⁶ His assumption that the reader is not familiar with Schrödinger’s exact description allows him these creative liberties.

Although Schrödinger’s cat ‘is arguably more famous than his equation’,⁴⁷ in textbooks, the reader is often immediately introduced to the Schrödinger equations: the time-dependent Schrödinger equation (TDSE, $i\hbar \frac{\partial}{\partial t} \Psi = \hat{H}\Psi$) and the time-independent Schrödinger equation (TISE, $E\Psi = \hat{H}\Psi$). The TDSE is the most general form, and is therefore often referred to as ‘the Schrödinger equation’. The first five editions of Rae’s *Quantum Mechanics*, James Binney and David Skinner’s textbook *The Physics of Quantum Mechanics*, and Stephen Gasiorowicz’s textbook *Quantum Mechanics*, which are all aimed at undergraduate students, cover both equations in the first chapter.⁴⁸ As

⁴⁴ ‘Explosion [...] der pulverisierten Katze’. Albert Einstein, ‘16. Einstein an Schrödinger’, in *Briefe zur Wellenmechanik*, ed. K. Pzibram (Berlin: Springer-Verlag, 1963), 32–33, <http://www.springer.com/gp/book/9783642520266>, p. 32. There is a horrifying irony to Schrödinger’s 1935 choice for hydrocyanic acid: seven years later, under the now infamous brand name Zyklon B, this substance was used in the gas chambers of Nazi Germany. Schrödinger, an atheist Austrian, had moved to Oxford in 1934, repulsed by the anti-Semitic sentiment of the Nazi party.

⁴⁵ Rae, *Illusion or Reality?*, 1986, 59; Rae, *A Beginner’s Guide*, 188; Rae and Napolitano, *Quantum Mechanics*, 388.

⁴⁶ From a more down-to-earth point of view, both an explosion and a gun would be much less practical than a flask of cyanide, because the box would have to be impressively shock- and soundproof to keep the cat in an unobserved superposition until the box is opened.

⁴⁷ Orzel, *How to Teach Quantum Physics to Your Dog*, 94.

⁴⁸ Alastair I. M. Rae, *Quantum Mechanics*, 1980. 5th ed. (New York: Taylor & Francis, 2008), 15; James Binney and David Skinner, *The Physics of Quantum Mechanics* (Oxford: Oxford University Press, 2014),

Velentzas et al. have shown, Schrödinger's cat paradox is not covered at all in more general physics textbooks.⁴⁹ In specialist textbooks, the cat is deferred to the final chapter if it is discussed at all.⁵⁰

Conversely, the Schrödinger equations are nearly always left out of popularizations. This is not unexpected: many popular science books pride themselves on being largely or even entirely equation- or maths-free, as Hawking's claim in *A Brief History of Time* illustrates: 'Someone told me that each equation I included in the book would halve the sales. I therefore resolved not to have any equations at all.'⁵¹ The popularizations I discuss here do contain some equations, yet the Schrödinger equation seems to have been considered too complicated to be included. Gribbin, Orzel, and Rae all discuss the Schrödinger equations without showing them.⁵² As Rae explains in *Illusion or Reality*, 'A proper understanding of this point requires a mathematical analysis that is well beyond the scope of this book', even though he does show the reader the equation expressing Heisenberg's uncertainty principle.⁵³ I have identified only two quantum physics popularizations that include the TDSE: Cox and Forshaw in *The Quantum Uni-*

31; Stephen Gasiorowicz, *Quantum Physics*, 1974. 3rd ed. (Hoboken, NJ: Wiley, 2003), 30; Rae and Napolitano, *Quantum Mechanics*, 61. In the sixth edition, the TDSE is not introduced in the first chapter, because Rae and Napolitano inserted several introductory chapters that review prerequisites; these precede the first chapter that covers quantum mechanics, which introduces the equation.

⁴⁹ Velentzas, Halkia, and Skordoulis, 'Thought Experiments', 363.

⁵⁰ Gasiorowicz, *Quantum Physics*, 327; Rae, *Quantum Mechanics*, 308; Binney and Skinner, *The Physics of Quantum Mechanics*, 158.

⁵¹ Hawking, *A Brief History of Time*, ix; The remark was made by Cambridge University Press editor Simon Mitton, as reported in Michael White and John Gribbin, *Stephen Hawking: A Life in Science*, 1992. New updated edition (London: Penguin, 2002), 243.

⁵² Gribbin, *In Search of Schrödinger's Cat*, 151–55; Orzel, *How to Teach Quantum Physics to Your Dog*, 72–73; Rae, *A Beginner's Guide*, 50–51.

⁵³ Rae, *Illusion or Reality?*, 1986, 11, 13.

verse and J.P. McEvoy and Oscar Zarate in *A Graphic Guide* both present it as ‘the’ Schrödinger equation.⁵⁴ No popularizations refer to the TISE. Cox and Forshaw in particular seem to include the equation only to show it off, as they do not provide a full explanation, nor is it part of their narrative: ‘The details of the equation are irrelevant for our purposes because we are not going to follow the Schrödinger approach in this book.’⁵⁵ Even though they adhere to the many-worlds rather than the Copenhagen interpretation in this book, about which more is to follow, Cox and Forshaw find it important to teach the reader to recognize the equation. Their approach of showing what is arguably the most important equation in the theory, without explaining exactly what the different elements of this equation mean, resembles the way $E=mc^2$ has been ingrained in popular memory, recognized by many who would not be able to explain its contents.⁵⁶ McEvoy and Zarate, on the other hand, do explain what every symbol in the equation means, and like a textbook, they introduce this equation before they discuss the cat paradox. However, they demand much more prerequisite knowledge than any other popularization does: the reader to whom this equation is explained should have a working knowledge of pre-university calculus concepts such as the second derivative.⁵⁷ McEvoy and Zarate is the only popularization discussed here that does not claim in any way to avoid mathematics, and indeed, for some sections, such as the explanation of Heisenberg’s matrix mechanics, the reader needs university-level mathematics.⁵⁸ That these authors still consider their work to be accessible to laypeople rather

⁵⁴ Cox and Forshaw, *The Quantum Universe*, 41; J. P. McEvoy and Oscar Zarate, *Quantum Theory: A Graphic Guide* (1996; repr., Thriplow: Icon, 2007), 134. The original 1996 title of McEvoy and Zarate’s book is *Quantum Theory for Beginners*.

⁵⁵ Cox and Forshaw, *The Quantum Universe*, 41.

⁵⁶ Cox and Forshaw have written another popularization about this very equation: Brian Cox and Jeff Forshaw, *Why Does $E=mc^2$? (And Why Should We Care?)* (New York: Da Capo Press, 2010).

⁵⁷ McEvoy and Zarate, *Quantum Theory: A Graphic Guide*, 134.

⁵⁸ McEvoy and Zarate, 129.

than being a semipopular work can be seen in their recommendation of Gribbin's *In Search of Schrödinger's Cat* at the end of the book: 'Until now, this was the best lay person's guide to how the theory emerged.'⁵⁹

As a semipopular work, Susskind and Friedman's *The Theoretical Minimum* positions itself neatly between the textbook treatments of the Schrödinger equations and the popular treatment of Schrödinger's cat. Susskind and Friedman focus on the equations, rather than on the cat, but do assume that the reader is familiar with the cat. When explaining the TDSE, they write it in Dirac's bra-ket notation⁶⁰ as $\frac{\partial |\Psi\rangle}{\partial t} = -i\mathbf{H}|\Psi\rangle$. They call the state vector ket $|\Psi\rangle$ 'Schrödinger's Ket'.⁶¹ McMahon starts his book with the Schrödinger equation just like regular textbooks, but does have a flippant cat paradox reference on its cover.

Rae's popularizations contain a relatively large proportion of mathematical content; even so, he claims in the preface to *Illusion or Reality?* that the book does not require 'either a thorough understanding of the wide areas of physics to which quantum theory has been applied or a great competence in the mathematical techniques that professionals find so useful.'⁶² This work contains several equations, which require an understanding of trigonometry; the most equation-heavy chapter is the one on hidden variables, which contains eleven numbered equations and several calculations in which they are used. This chapter is preceded by a warning, though: 'The arguments

⁵⁹ McEvoy and Zarate, 174.

⁶⁰ P. A. M. Dirac, 'A New Notation for Quantum Mechanics', *Mathematical Proceedings of the Cambridge Philosophical Society* 35, no. 3 (July 1939): 416–18, <https://doi.org/10.1017/S0305004100021162>.

⁶¹ Susskind and Friedman, *Quantum Mechanics*, 2015, 102.

⁶² Rae, *Illusion or Reality?*, 1986, ix.

underlying these conclusions are discussed in this chapter; unfortunately they are unavoidably rather more complex and technical than those in the rest of this book, but they are very important and worth the effort that may be required.’⁶³

Encountering equations is optional in Rae’s second popularization. Notably, *Illusion or Reality* was published before Stephen Hawking made his aforementioned claim about halving sales. *A Brief History of Time* may have been instrumental in normalizing the absence of mathematics in physics popularizations. In *A Beginner’s Guide*, Rae sections off his mathematical content in ‘mathematical boxes’. As he explains in his introduction, ‘These [equations] are not essential to our discussion, but readers who are more comfortable with mathematics may find them interesting and helpful.’⁶⁴ It is in fact not necessary to be familiar or comfortable with mathematics at all for the first box, which ‘at the risk of offending the more numerate reader’ explains what an equation is, and how multiplication, division, and powers are written.⁶⁵ Rae shows that he is more willing to estrange a mathematically literate reader than a beginner: in his books, knowing mathematics is a marker of otherness. The more complex content is present for those willing to engage, but can be ignored by those who are only interested in the story: the narrative has become entirely dissociated from the mathematics.

The way in which Schrödinger’s work is treated in popular physics, then, depends strongly on the assumptions the authors make about what their readership already knows and which parts of quantum physics they are interested in: the story of the cat is often used as the thread which ties the book together. The equations are of secondary importance: authors usually do not include them because they wish to avoid

⁶³ Rae, 28.

⁶⁴ Rae, *A Beginner’s Guide*, 6.

⁶⁵ Rae, 7.

equations altogether, and instead offer a qualitative discussion. If they do include them, they either simply show them off to the reader as an object worthy of admiration, or they assume that the readers possess significant background knowledge in mathematics and physics.

Surprisingly, not all elements of a popularization are selected based on readers' prior knowledge or interests. The authors choose the interpretation, or interpretations, of quantum physics that are addressed in the popularization based solely on their personal preferences; other interpretations are either ignored or described in negative terms.

Interpretations of Quantum Physics

The sheer number of different interpretations of quantum physics causes most of them to be omitted from both textbooks and popular science books.⁶⁶ The focus usually lies on the Copenhagen interpretation and the many-worlds interpretation. Popularizers tend to express a clear preference for an interpretation, usually one of these two, which leads to two different kinds of scientific stories told in popularizations: stories of conflict and stories of agreement.

Table 1 gives an overview of the major popularizations of quantum physics from the 1980s onwards, indicating which interpretation(s) of quantum physics the authors discuss, and whether they do so in a positive or negative manner. The table shows that

⁶⁶ The Internet Encyclopedia of Philosophy lists eight interpretations; Wikipedia lists seventeen. Peter J. Lewis, 'Interpretations of Quantum Mechanics', Internet Encyclopedia of Philosophy, accessed 17 March 2017, <http://www.iep.utm.edu/int-qm/#H6>; 'Interpretations of Quantum Mechanics', *Wikipedia*, 2 March 2017, https://en.wikipedia.org/w/index.php?title=Interpretations_of_quantum_mechanics.

for decades, popular quantum physics works displayed a roughly 50/50 divide between endorsing many-worlds and endorsing Copenhagen, whereas among practicing quantum physicists the proportion of many-worlds supporters has always been much smaller. The most recent quantum physics popularizations, from the 2010s, make a point of rejecting both the Copenhagen and the many-worlds interpretation before endorsing newer interpretations, showing the lasting effect of the widespread popularization of these two interpretations.

Table 1: Popular quantum physics books written by physicists and the interpretations they adhere to, 1979-present. + indicates endorsement, - indicates rejection, +/- indicates ambivalence, and 0 indicates a neutral stance.

Book	Copenhagen	Many-worlds	Other
Gary Zukav, <i>The Dancing Wu Li Masters</i> (1979) ⁶⁷	+	-	
Paul Davies, <i>Other Worlds</i> (1980) ⁶⁸	-	+	+ conscious collapse
Heinz R. Pagels, <i>The Cosmic Code</i> (1982) ⁶⁹	-	-	- 'quantum logic' (now QBism ⁷⁰) - conscious collapse + 'shut up and calculate'
John Gribbin, <i>In Search of Schrödinger's Cat</i> (1984) ⁷¹	-	+	
Alastair I. M. Rae, <i>Quantum physics: illusion or reality?</i> (1986) ⁷²	+	-	

⁶⁷ Gary Zukav, *The Dancing Wu Li Masters: An Overview of the New Physics* (London: Rider & Hutchinson, 1979).

⁶⁸ Paul Davies, *Other Worlds: Space, Superspace, and the Quantum Universe* (1980; repr., London: Penguin Books, 1990).

⁶⁹ Heinz R. Pagels, *The Cosmic Code: Quantum Physics as the Language of Nature* (1982; repr., London: Michael Joseph, 1983).

⁷⁰ Carlton M. Caves, Christopher A. Fuchs, and Rüdiger Schack, 'Quantum Probabilities as Bayesian Probabilities', *Physical Review A* 65, no. 2 (4 January 2002): 022305, <https://doi.org/10.1103/PhysRevA.65.022305>.

⁷¹ Gribbin, *In Search of Schrödinger's Cat*.

⁷² Rae, *Illusion or Reality?*, 1986.

Tony Hey and Patrick Walters, <i>The Quantum Universe</i> (1987) ⁷³	[absent]	[absent]	
Robert Gilmore, <i>Alice in Quantumland</i> (1995) ⁷⁴	+	-	- conscious collapse - hidden variables
John Gribbin, <i>Schrödinger's Kittens</i> (1995) ⁷⁵	-	+/-	+ transactional interpretation ⁷⁶
J.P. McEvoy and Oscar Zarate, <i>Quantum Theory for Beginners</i> (1996) ⁷⁷	+	[absent]	- conscious collapse
Robert Gilmore, <i>Scrooge's Cryptic Carol</i> (1996) ⁷⁸	0	+	
David Deutsch, <i>The Fabric of Reality</i> (1997) ⁷⁹	-	+	
Terry Pratchett, John Gribbin, and Ian Stewart, <i>The Science of Discworld</i> (1999-2013) ⁸⁰	-	-	+ sum over histories
John Polkinghorne, <i>Quantum Theory</i> (2002) ⁸¹	+	[absent]	
John Gribbin, <i>quantum physics</i> (2002) ⁸²	0	[absent]	
Tony Hey and Patrick Walters, <i>The New Quantum Universe</i> (2003) ⁸³	+/-	-	0 conscious collapse

⁷³ Tony Hey and Patrick Walters, *The Quantum Universe* (Cambridge: Cambridge University Press, 1987).

⁷⁴ Gilmore, *Alice in Quantumland*.

⁷⁵ John Gribbin, *Schrödinger's Kittens and the Search for Reality* (London: Weidenfeld and Nicolson, 1995).

⁷⁶ John G. Cramer, 'The Transactional Interpretation of Quantum Mechanics', *Reviews of Modern Physics* 58, no. 3 (1 July 1986): 647–87, <https://doi.org/10.1103/RevModPhys.58.647>.

⁷⁷ J. P. McEvoy and Oscar Zarate, *Quantum Theory for Beginners* (New York: Totem Books, 1996).

⁷⁸ Robert Gilmore, *Scrooge's Cryptic Carol: Visions of Energy, Time, and Quantum Nature* (New York: Copernicus, 1996).

⁷⁹ Deutsch, *The Fabric of Reality*.

⁸⁰ Terry Pratchett, Ian Stewart, and Jack Cohen, *The Science of Discworld*, 1999. Revised ed. (London: Ebury, 2002); Terry Pratchett, Ian Stewart, and Jack Cohen, *The Science of Discworld II: The Globe* (2002; repr., London: Ebury, 2013); Terry Pratchett, Ian Stewart, and Jack Cohen, *The Science of Discworld III: Darwin's Watch* (2005; repr., London: Ebury, 2013); Terry Pratchett, Ian Stewart, and Jack Cohen, *The Science of Discworld IV: Judgement Day* (London: Ebury, 2013).

⁸¹ John Polkinghorne, *Quantum Theory: A Very Short Introduction* (Oxford: Oxford University Press, 2002).

⁸² John Gribbin, *quantum physics: a beginner's guide to the subatomic world* (London: Dorling Kindersley, 2002).

⁸³ Tony Hey and Patrick Walters, *The New Quantum Universe* (Cambridge: Cambridge University Press, 2003).

Jim Al-Khalili, <i>Quantum</i> (2003) ⁸⁴	-	+/-	+ 'shut up and calculate' - hidden variables
Alastair I. M. Rae, <i>Quantum Physics</i> (2005) ⁸⁵	+	-	- subjectivism - hidden variables
Marcus Chown, <i>Quantum Theory Cannot Hurt You</i> (2005) ⁸⁶	-	0	
Chad Orzel, <i>How to Teach Quantum Physics to your Dog</i> (2010) ⁸⁷	-	+	+ 'shut up and calculate'
Brian Cox and Jeff Forshaw, <i>The Quantum Universe</i> (2011) ⁸⁸	[absent]	+	
Jim Baggott, <i>The Quantum Story</i> (2011) ⁸⁹	-	-	- decoherent histories
Amanda Gefter, <i>Trespassing on Einstein's Lawn</i> (2014) ⁹⁰	-	-	- conscious collapse + information-theoretic interpretation
Jeffrey Bub, <i>Bananaworld</i> (2016) ⁹¹	-	-	+ information-theoretic interpretation
Hans Christian von Bayer, <i>QBism</i> (2016) ⁹²	-	-	- pilot-wave - spontaneous collapse + QBism
Michael G. Raymer, <i>Quantum Physics</i> (2017) ⁹³	+/-	-	- QBism

⁸⁴ Jim Al-Khalili, *Quantum* (London: Weidenfeld & Nicolson, 2003).

⁸⁵ Rae, *A Beginner's Guide*.

⁸⁶ Marcus Chown, *Quantum Theory Cannot Hurt You: A Guide to the Universe* (2005; repr., London: Faber, 2008).

⁸⁷ Orzel, *How to Teach Quantum Physics to Your Dog*.

⁸⁸ Cox and Forshaw, *The Quantum Universe*.

⁸⁹ Baggott, *The Quantum Story*.

⁹⁰ Amanda Gefter, *Trespassing on Einstein's Lawn: A Father, a Daughter, the Meaning of Nothing, and the Beginning of Everything* (New York: Bantam Books, 2014).

⁹¹ Jeffrey Bub, *Bananaworld: Quantum Mechanics for Primates* (Oxford: Oxford University Press, 2016).

⁹² Hans Christian von Baeyer, *QBism: The Future of Quantum Physics* (Cambridge, MA: Harvard University Press, 2016).

⁹³ Michael G. Raymer, *Quantum Physics: What Everyone Needs to Know* (New York: Oxford University Press, 2017). Raymer distinguishes between 'the Everett interpretation', which is Everett's original interpretation, and 'the many-worlds interpretation', which is Deutsch's updated version; he expresses scepticism about both.

John Gribbin, for instance, is upfront about his personal preference for this interpretation in *In Search of Schrödinger's Cat*. He starts his chapter titled 'Many Worlds' by stating,

Until now, I have tried not to take sides in this book [...] Now the time has come to stand up and be counted. In this final chapter I abandon any pretence of impartiality and present the interpretation of quantum mechanics that I find the most satisfactory and pleasing. This is not the majority view; most of the physicists who bother to think about such things at all are happy with the collapsing wave functions of the Copenhagen interpretation. But it is a respectable minority view [...].⁹⁴

Gribbin claims that the Copenhagen interpretation is the most widely supported one at the time of writing in the 1980s, even though it is not his personal favourite. He sets up the many-worlds interpretation as an underdog, arguing that the theory has been neglected for too long, and continues to be unjustly overlooked. He points out twice that Everett's many-worlds interpretation was largely ignored until Bryce DeWitt took it up in the late 1960s, claiming that it 'made scarcely a ripple as it fell into the pool of scientific knowledge in 1957' and that it 'was almost studiously ignored by the physics community'.⁹⁵ Gribbin evokes emotion to gain support for the theory, rather than relying on the idea of acceptance by scientific peers as a measure of credibility. Having presented himself as a reliable expert physicist throughout the book up to this point, by showing that he is able to explain the very complex concepts of quantum physics, Gribbin now asks the reader to trust his judgement completely regarding the credibility of the many-worlds interpretation.

Orzel and his dog similarly express clear preferences. Emmy says about the Copenhagen interpretation, 'I don't think I like this interpretation. It's awfully solipsistic,

⁹⁴ Gribbin, *In Search of Schrödinger's Cat*, 300.

⁹⁵ Gribbin, 307, 310.

isn't it?' Orzel tells her that 'There aren't very many physicists these days who are really happy with the Copenhagen interpretation', and that he prefers Feynman's "'shut up and calculate" interpretation."⁹⁶ He then introduces several alternatives to Emmy, who decides, 'I like the many-worlds interpretation. You should talk about that.'⁹⁷ Having the author and his dog, who stand for the expert physicist and the reader, together decide that they dislike the Copenhagen interpretation, is likely to lead to a bias on the reader's side. However, what is not explained in this book is the fact that what Orzel calls the 'shut up and calculate' interpretation is actually a formalist approach to the Copenhagen interpretation. Although the term is commonly attributed to Feynman, the phrase seems to have been coined by N. David Mermin as a criticism of the Copenhagen interpretation: 'If I were forced to sum up in one sentence what the Copenhagen interpretation says to me, it would be "Shut up and calculate!"'⁹⁸ Orzel's exposition suggests to the reader that one fortunately does not always have to think about these many complex interpretations, but if one does, many-worlds sounds nicest.

In his new epilogue to the 2012 edition of *In Search of Schrödinger's Cat*, Gribbin argues that the many-worlds interpretation has become mainstream since the 1980s: 'from being "a respectable minority view" to such a mainstream position that it is often simply referred to by the initials MWI, which all physicists recognise.'⁹⁹ This epilogue is written after the publication of Orzel's book; notably, Orzel does not consider the many-worlds interpretation to be mainstream even though he prefers it over Copen-

⁹⁶ Orzel, *How to Teach Quantum Physics to Your Dog*, 96.

⁹⁷ Orzel, 97.

⁹⁸ N. David Mermin, 'Could Feynman Have Said This?', *Physics Today* 57, no. 5 (1 May 2004): 10–11, <https://doi.org/10.1063/1.1768652>; N. David Mermin, 'What's Wrong with This Pillow?', *Physics Today* 42, no. 4 (April 1989): 9, 11, <https://doi.org/10.1063/1.2810963>.

⁹⁹ Gribbin, *In Search of Schrödinger's Cat*, 351.

hagen. Gribbin completes the heroic underdog story with a happy ending: though David did not defeat Goliath, he is now considered an equal giant. Gribbin does not mention that the many-worlds interpretation is still not taken up in undergraduate quantum physics textbooks, and thus cannot be considered fully mainstream yet. He has switched to the rhetoric of the mainstream, emphasizing that other famous scientists also support the many-worlds interpretation: ‘In the 1980s and 1990s, the idea received a boost from cosmologists, famously including Stephen Hawking [...]. But cosmology is a rather esoteric discipline [...] the real reason for the resurgence of the MWI was the development of quantum computing, and in particular the work of Oxford physicist David Deutsch.’¹⁰⁰

Gribbin’s defensive epilogue from 2012 comes as a surprise to those who have read his 1995 popularization *Schrödinger’s Kittens and the Search for Reality*, a sequel to *In Search of Schrödinger’s Cat* that addressed new developments in quantum physics that had taken place over the intervening decade. In this work, he claimed that ‘an even better interpretation [...] has appeared [...]. I am no longer *quite* so enthusiastic about the many-worlds interpretation as I used to be, but it is still at least as good as the Copenhagen Interpretation’.¹⁰¹ In *Schrödinger’s Kittens*, Gribbin favours what is now known as the ‘transactional interpretation’, first proposed by John Cramer in 1986.¹⁰²

In spite of his affiliations with the transactional and many-worlds interpretations, Gribbin has also popularised the Copenhagen interpretation. In between *Schrödinger’s Kittens* and the 2012 epilogue to *In Search of Schrödinger’s Cat*, he published a very short (72 pages) Dorling Kindersley book titled *quantum physics: a beginner’s*

¹⁰⁰ Gribbin, 352.

¹⁰¹ Gribbin, *Schrödinger’s Kittens*, 160–61.

¹⁰² Gribbin, 223–47; Cramer, ‘The Transactional Interpretation of Quantum Mechanics’.

guide to the subatomic world in which he discusses only the Copenhagen interpretation, without offering an opinion; both the length of the work and the encyclopaedic style of Dorling Kindersley works may have contributed to the omission of contending interpretations.¹⁰³

David Deutsch popularized the many-worlds interpretation in *The Fabric of Reality* (1997), shortly after Gribbin published *Schrödinger's Kittens*, which suggests that his work may have helped to change Gribbin's mind in favour of many-worlds again. In a lengthy section in which he explains why the many-worlds interpretation is a minority view, Deutsch claims that it is too deep and disturbing for most physicists:

The heart of the argument is that single-particle interference phenomena unequivocally rule out the possibility that the tangible universe around us is all that exists. There is no disputing the fact that such interference phenomena occur. Yet the existence of the multiverse is still a minority view among physicists. Why?

The answer, I regret to say, does not reflect well upon the majority. [...] the arguments I have presented in this chapter are compelling only to those who seek explanations. Those who are satisfied with mere prediction, and who have no strong desire to understand how the predicted outcomes of experiments come about, may if they wish simply deny the existence of anything other than what I have been calling 'tangible' entities. Some people, such as instrumentalists and positivists, take this line as a matter of philosophical principle. I have already said what I think of such principles, and why. Other people just don't want to think about it. After all, it is such a large conclusion, and such a disturbing one on first hearing. But I think that those people are making a mistake.¹⁰⁴

Deutsch suggests that he is giving his readers the possibility of engaging with more complex concepts than the average quantum physicist can handle. He does not mention the Copenhagen interpretation until page 327. Yet in the chapter quoted from above, he has just presented the many-worlds interpretation as the only possible explanation

¹⁰³ Gribbin, *quantum physics*. Capitalization of the title *sic*.

¹⁰⁴ Deutsch, *The Fabric of Reality*, 47–48.

of the effects to be observed in the double-slit experiment: in 1807 Thomas Young described shining a focused beam of light through a piece of cardboard with two slits in it; projected behind the two slits one will see an interference pattern, proving the wave-like nature of light.¹⁰⁵

To a reader introduced to quantum theory in this way, it would be difficult to imagine how it is possible to work with quantum physics at all without applying the many-worlds interpretation. Deutsch's explanation of the Copenhagen interpretation reinforces this idea, as he presents it as outdated:

We need not concern ourselves here with the arcane details of the Copenhagen interpretation, because its motivation was essentially to avoid the conclusion that reality is multi-valued, and for that reason alone it is incompatible with any genuine explanation of quantum phenomena.¹⁰⁶

The many-worlds interpretation is presented as a minority view, but not as an underdog theory that people should pity; it is new, revolutionary and the *only* possible interpretation, and those who still adhere to Copenhagen are wrong and outdated.

Cox and Forshaw take an approach similar to Deutsch in their exclusive focus on the many-worlds interpretation, which to the knowledgeable reader is already visible in the subtitle of their book, 'Everything that can happen does happen'. However, it might still come as a surprise that they neither mention the Copenhagen interpretation at all, nor mention Everett's name. In their tenth chapter, they finally explain that 'the approach to quantum mechanics we have been discussing [...] forms the basis of what is often referred to as the "many worlds" interpretation.' In contrast, they write, 'the "shut up and calculate" school of physics [...] deftly dismisses any attempt to talk

¹⁰⁵ Thomas Young, *A Course of Lectures on Natural Philosophy and the Mechanical Arts*, vol. 1 (London: J. Johnson, 1807), 464–65, <http://www.biodiversitylibrary.org/item/63005>.

¹⁰⁶ Deutsch, *The Fabric of Reality*, 328.

about the reality of things.¹⁰⁷ They do not return to this ‘school’ again, so it is not clear whether they mean the Copenhagen interpretation as a whole or the narrower instrumentalist approach championed by Feynman. Cox and Forshaw thus do not write a conflict narrative, as Orzel, Gribbin and Deutsch do. They do not present the many-worlds interpretation as a worthy interpretation overshadowed by Copenhagen, but simply as the only one worth communicating. This does mean, however, that they miss out on discussing the most famous criticism of the Copenhagen interpretation: Schrödinger’s cat, which is only in a superposition of being both dead and alive in this interpretation. As mentioned above, the cat is not included in their work at all.

When reading either of Rae’s popularizations, or McEvoy and Zarate, the reader might instead be led to support the Copenhagen interpretation. McEvoy and Zarate do not mention any interpretations other than the Copenhagen interpretation, which they shorten to CHI: ‘After this incident [Bohr’s refutation of Einstein’s “box of light” argument], CHI became the orthodox way of viewing quantum theory, and has lasted to the present day.’¹⁰⁸

Rae, on the other hand, creates a conflict narrative in *Illusion or Reality?* He first introduces the Copenhagen interpretation, then the many-worlds interpretation, and subsequently tells the reader:

Despite all we have said, it would be surprising if many readers have been convinced of the plausibility of many-worlds theory. In the vast majority of the universes that have evolved since you began reading this chapter, you are completely sceptical about the idea!¹⁰⁹

¹⁰⁷ Cox and Forshaw, *The Quantum Universe*, 188–89.

¹⁰⁸ McEvoy and Zarate, *Quantum Theory: A Graphic Guide*, 165.

¹⁰⁹ Rae, *Illusion or Reality?*, 1986, 81.

He refers to another famous physicist and popularizer, Paul Davies, to support his views against the many-worlds interpretation: “To adapt Paul Davies’s words, most would believe that the losses involved in the “extravagance with universes” heavily outweigh the gains from the “economy with postulates”.’¹¹⁰ However, Paul Davies is actually positive about the many-worlds interpretation in comparison with Copenhagen in his 1980 popularization *Other Worlds*.¹¹¹

Rae’s more recent popularization *A Beginner’s Guide* introduces the Copenhagen interpretation as ‘the conventional view among physicists. Some alternative approaches are discussed briefly towards the end of the chapter.’¹¹² One of these ‘alternative approaches’ is the many-worlds interpretation, about which Rae writes that ‘the model has not won a consensus in the scientific community.’¹¹³ Whereas the adherents of the many-worlds interpretation highlight its outlier status as a positive characteristic, giving the reader the feeling that they are learning about a theory so revolutionary not even all physicists have caught up with it, Rae emphasizes this status as the reason why the reader should not bother with it: it is not part of established scientific theory; Rae, therefore, will not trouble the reader with minor conjectures.

Depending on which popularization the reader chooses, then, they will end up with quite different views regarding the scientific community’s position with regard to interpretations of quantum physics. However, with a large proportion of popular

¹¹⁰ Rae, 81.

¹¹¹ Davies, *Other Worlds: Space, Superspace, and the Quantum Universe*, 126–27.

¹¹² Rae, *A Beginner’s Guide*, 176.

¹¹³ Rae, 199.

works endorsing the many-worlds interpretation, it is no surprise that this interpretation has crossed over into a large number of fictional works, such as Philip Pullman's *His Dark Materials* and Iain Pears's *Arcadia*, which will be discussed in later chapters.

In his textbook, Rae explains both interpretations in the final chapter, in which he shows some of the ways in which physicists have attempted to explain wavefunction collapse. Surprisingly, he mentions the many-worlds interpretation first. However, Rae clearly disagrees with it, writing this section in a very argumentative style that is unusual for a textbook:

Many-worlds theory addresses many of the problems associated with the quantum theory of measurement, but it does so in a particularly uneconomical manner. The idea [...] seems to be an extreme breach of [Occam's razor]. Nevertheless, this idea is taken seriously by some very serious people and it at least deserves further consideration of its merits.¹¹⁴

Rae is not uncritical of the Copenhagen interpretation either, although he does not attack it so fiercely:

despite its great insights, the Copenhagen interpretation really does not address the problem of what constitutes a quantum measurement [...] from the Copenhagen/consistent histories point of view, the Cartesian programme is not complete and never will be.¹¹⁵

Rae, then, argues that there are many different interpretations, and even though none of them have so far solved all of the problems in quantum physics, some interpretations he finds better than others.

Rae's approach is uncommon for textbooks, as they usually avoid a conflict narrative. Binney and Skinner teach the Copenhagen interpretation, introducing its name

¹¹⁴ Rae, *Quantum Mechanics*, 311; Rae and Napolitano, *Quantum Mechanics*, 391.

¹¹⁵ Rae, *Quantum Mechanics*, 317–18.

nearly halfway through the book: ‘When we laid the foundations of quantum mechanics in §1.2, we focused on “ideal” measurements [...] This scheme is known as the Copenhagen interpretation of quantum mechanics because it was thrashed out in Niels Bohr’s institute in Copenhagen.’¹¹⁶ They do not name any other interpretations. Messiah, for his part, does not mention the names of either the Copenhagen interpretation or the many-worlds interpretation in his 1100-page textbook; he instead supports what he calls the ‘statistical interpretation’, or ensemble interpretation.¹¹⁷ The semi-popular works side with the textbooks on this issue: neither Susskind and Friedman nor McMahon mention any interpretations other than the one that is taught, Copenhagen, which is not named as such. Omitting the name of the interpretation facilitates presenting it as the only one in existence.

Philosophy and Mysticism

The conceptual implications of quantum physics, which have been addressed at length by philosophers,¹¹⁸ are often omitted from popularizations, and nearly always from textbooks. Many physicist popularizers are strongly sceptical of philosophy: as I will discuss further in the chapter on scientific conflict, Stephen Hawking speaks rather derogatorily about philosophers, until he uses Popper to support his own views regarding scientific development. This anti-philosophical attitude has pervaded popularizations

¹¹⁶ Binney and Skinner, *The Physics of Quantum Mechanics*, 158.

¹¹⁷ Albert Messiah, *Quantum Mechanics*, trans. G.M. Temmer, vol. 1 (1961; repr., Amsterdam: North-Holland, 1985), 115; Max Born, ‘The Statistical Interpretation of Quantum Mechanics’, *Nobel Lecture, Nobelprize.org*, 11 December 1954, https://www.nobelprize.org/nobel_prizes/physics/laureates/1954/born-lecture.pdf.

¹¹⁸ Influential philosophical works that have addressed conceptual problems in quantum physics include Rob Clifton, ed., *Perspectives on Quantum Reality: Non-Relativistic, Relativistic, and Field-Theoretic* (Dordrecht: Kluwer Academic Publishers, 1996); Simon Saunders et al., eds., *Many Worlds? Everett, Quantum Theory, and Reality* (Oxford: Oxford University Press, 2010); Wallace, *The Emergent Multiverse*.

of quantum physics since their first inception. *Mr Tompkins in Wonderland* contains the following exchange:

‘Well, well,’ exclaimed Mr Tompkins, ‘it certainly looks like philosophy to me!’
 ‘You can call it philosophy if you like’ – the professor was evidently offended –
 ‘but as a matter of fact, this is the fundamental principle of modern physics –
never to speak about the things you cannot know. All modern physical theory is
 based on this principle, whereas the philosophers usually overlook it.’¹¹⁹

The professor then gives Kant as an example of one such philosopher.

The relation between physics and philosophy on the subject of quantum physics has historically been problematic. Many of the original physicists who worked on quantum theory expressed a personal interest in philosophy and its relation to quantum physics; Werner Heisenberg, for instance, published a work on the philosophical implications of his physics theories. Unfortunately, he seems to have pursued this topic without enough formal knowledge of the philosophy or history of science. His *Physics and Philosophy: The Revolution in Modern Science* (1959), a book ‘for the layman’ which is based on a series of lectures,¹²⁰ was rejected by philosophers and physicists alike for the many mistakes it contained. A representative view is that of Heisenberg’s colleague Léon Rosenfeld, whose review in *Nature* claimed that the book displays ‘serious inaccuracies’ and is ‘positively misleading’.¹²¹

Many of the earliest popularizations similarly showed little regard for the formal discipline of philosophy, something which may well have been detrimental to any future considerations of philosophy in physics popularizations. Philosophy very often got tarred with mysticism, and many mysticist works on quantum physics make use of

¹¹⁹ Gamow, *Mr Tompkins in Wonderland*, 32.

¹²⁰ F.S.C. Northrop, ‘Introduction’, in *Physics and Philosophy: The Revolution in Modern Science*, by Werner Heisenberg (1958; repr., London: George Allen & Unwin Ltd., 1959), 11.

¹²¹ L. Rosenfeld, ‘Heisenberg, Physics and Philosophy’, *Nature* 186, no. 4728 (11 June 1960): 830–31.

the term 'philosophy' in this incorrect manner. Quantum physics is not the first scientific field to encounter such misinterpretations. Beer explains how new findings in astrophysics were hijacked as explanations of paranormal phenomena:

Tyndall's making visible, in his theoretical and experimental demonstrations, of the 'dark rays' of the sun was – for some beholders – not unlike the appearance of the aura in spiritualism. Azure and wave motion, the stirring topics of then current scientific enquiry, enter early modernism alongside spiritual emanations. If ether, why not aura? If dark rays, why not invisible presences?¹²²

As Elizabeth Leane discusses in *Reading Popular Physics*, Fritjof Capra's *The Tao of Physics* (1975) and Gary Zukav's *The Dancing Wu Li Masters* (1979) sparked a wide interest in the spiritual side of quantum physics, causing it to be linked to the New Age movement.¹²³ Several New Age works followed that make use of brief references to physics in order to justify non-scientific belief systems, such as Danah Zohar's *The Quantum Self* (1990) and *The Quantum Society* (1994), and Deepak Chopra's *Quantum Healing* (1989). Chopra, the most famous pseudoscientific interpreter of quantum physics, has been awarded an Ig Nobel prize 'for his unique interpretation of quantum physics as it applies to life, liberty, and the pursuit of economic happiness.'¹²⁴

Gribbin also touches on the relation between quantum physics and mysticism. As he writes in his introduction to *In Search of Schrödinger's Cat*, 'Quantum mechanics is identified in popular mythology, so far as it is identified at all, with the occult and ESP, some weird and esoteric branch of science that nobody understands and nobody

¹²² Gillian Beer, *Open Fields: Science in Cultural Encounter* (Oxford: Clarendon Press, 1996), 312.

¹²³ Leane, *Reading Popular Physics*, 31; Fritjof Capra, *The Tao of Physics: An Exploration of the Parallels between Modern Physics and Eastern Mysticism* (London: Wildwood House, 1975); Zukav, *The Dancing Wu Li Masters*.

¹²⁴ 'The 1998 Ig Nobel Prize Winners', accessed 12 January 2017, <http://www.improbable.com/ig/winners/#ig1998>. The Ig Nobel Prize is an award for scientific achievements 'that make people laugh, then think. Good achievements can also be odd, funny, and even absurd; So can bad achievements. A lot of good science gets attacked because of its absurdity. A lot of bad science gets revered despite its absurdity.' 'About The Ig® Nobel Prizes', Improbable Research, accessed 8 September 2017, <http://www.improbable.com/ig/>.

has any practical use for.’¹²⁵ Gribbin strongly emphasizes that Capra’s ‘excellent’ book is itself scientific and not to blame for ‘having spawned imitators who understood neither the physics nor the Tao but suspected there was money to be made out of linking western science with eastern philosophy.’¹²⁶ He is more careful about recommending Zukav:

In effect this book is a counterpart to Capra’s *The Tao of Physics*, telling the same story from the viewpoint of someone who is *not* a trained physicist. All scientists should read this, to find out what non-scientists make of the new physics, non-scientists are cautioned that Zukav sometimes lets his excitement get the better of him, that the science in the book is not always 100 percent accurate in its portrayal, and that, like Capra, he pays scant attention to the way the ideas developed.¹²⁷

Physicist Victor J. Stenger even dedicated an entire book to debunking various forms of misuse of quantum physics in theologies and mysticism, *Quantum Gods: Creation, Chaos and the Search for Cosmic Consciousness* (2009),¹²⁸ the title of which deliberately ‘sounds just crackpot enough to attract those readers who will benefit most’, according to Amanda Gefter’s review.¹²⁹ Orzel devotes his final chapter, ‘Beware of Evil Squirrels: Misuses of Quantum Physics,’ to a thorough debunking of several of these spiritualist usages of quantum physics, which he terms ‘quantum quackery’: the company Black Light Power (which is now called Brilliant Light Power), Chopra’s *Quantum Healing* (1989) and *Ageless Body, Timeless Mind* (1994), Jack Angelo’s *Distant Healing* (2008), Tiffany Snow’s *Forward from the Mind: Distant Healing, Bilocation, Medical Intuition & Prayer in a Quantum World* (2006), and a 2006 paper by the homeopath Lionel

¹²⁵ Gribbin, *In Search of Schrödinger’s Cat*, 15.

¹²⁶ Gribbin, 16.

¹²⁷ Gribbin, 371.

¹²⁸ Victor J. Stenger, *Quantum Gods: Creation, Chaos, and the Search for Cosmic Consciousness* (Amherst, NY: Prometheus Books, 2009).

¹²⁹ Amanda Gefter, ‘Review: Quantum Gods: Creation, Chaos and the Search for Cosmic Consciousness by Victor J. Stenger’, *New Scientist*, 18 April 2009, 46.

Milgrom.¹³⁰ Orzel's selection shows that Capra and Zukav's legacy in the New Age field lasted far beyond the decades in which their works were published, and mystical misinterpretations of quantum physics continue to appear: works written in this decade include Phil Mason's *Quantum Glory: The Science of Heaven Invading Earth* (2010), Lisa Romano's *Quantum Tools to Help You Heal Your Life Now* (2014), and Laura Berman's *Quantum Love: Use Your Body's Atomic Energy to Create the Relationship You Desire* (2016).¹³¹ One of the most influential of these more modern spiritual interpretations is the film *What the #\$*! Do We (K)now?!* (2004), which presents a fictional story as a documentary, exploring the links between quantum physics and consciousness.¹³² The fringe physicist Fred Alan Wolf, who is a member of the mysticist Fundamental Fysics Group together with Fritjof Capra, collaborated on this film, which grossed nearly \$11 million in the US alone in its first year.¹³³ Contemporary popularizations dialogically engage, in the Bakhtinian sense, with these works, as their authors must bear in mind that their readership may have encountered them.¹³⁴ In writing their popularizations, these scientists attempt to reframe the metaphysical works as emphatically non-scientific, as opposed to their own books.

¹³⁰ Orzel, *How to Teach Quantum Physics to Your Dog*, 253.

¹³¹ Phil Mason, *Quantum Glory: The Science of Heaven Invading Earth* (Maricopa, AZ: XP Publishing, 2010); Lisa Romano, *Quantum Tools to Help You Heal Your Life Now: Healing the Past Using the Secrets of the Law of Attraction* (Denver, CO: Outskirt Press, 2014); Laura Berman, *Quantum Love: Use Your Body's Atomic Energy to Create the Relationship You Desire* (London: Hay House, 2016).

¹³² William Arntz, Betsy Chasse, and Mark Vicente, *What the #\$*! Do We (K)Now!?*, AVI video (Vancouver: Lost Boys Studios, Inc., 2004).

¹³³ Peter Woit, 'Fun with Fysics', *American Scientist* 99, no. 4 (2011): 332, <https://doi.org/10.1511/2011.91.332>; 'The Minds Boggle', *The Guardian*, 16 May 2005, sec. Science, <https://www.theguardian.com/science/2005/may/16/g2.science>.

¹³⁴ Mikhail Bakhtin, *The Dialogic Imagination: Four Essays*, trans. Michael Holquist (Austin: University of Texas Press, 1981).

Most scientists considered these negative associations to have tainted the field to such an extent that they in their popularization no longer wished to associate themselves with the mystical, esoteric or philosophical implications of quantum physics, even if, as Leane notes,

they were nonetheless indebted to New Age popularizers for opening the market to all kinds of popular expositions of quantum theory. In the years following the publication of Capra's and Zukav's books, quantum physics emerged from the relative obscurity it had endured for half a century.¹³⁵

Rae is one of the few post-1970s popularizers who does include philosophy in his books, including in *A Beginner's Guide*, even though that book is intended to explain the practical applications of quantum physics. He explains the importance of mathematics in science by referring to Karl Popper: improved measurements, using numbers and therefore mathematics, lead to improved falsifiability.¹³⁶ However, Rae does suggest an opposition between Popperian science and philosophy with a bias in favour of science when he claims that 'a theory that is completely incapable of being disproved is often described as "metaphysical" or unscientific.'¹³⁷

Thomas Kuhn claimed that 'Even books that compete for adoption in a single course differ mainly in level and in pedagogic detail, not in substance or conceptual structure.'¹³⁸ In his textbook Rae complicates Kuhn's claim with his unusual decision to include the philosophical aspects of quantum physics: the final chapter in his book is dedicated entirely to 'The conceptual problems of quantum mechanics.' Kuhn proposes a view of textbooks as conveyors of normal science, yet different textbooks on

¹³⁵ Leane, *Reading Popular Physics*, 33–34.

¹³⁶ Rae, *A Beginner's Guide*, 5–6.

¹³⁷ Rae, 5.

¹³⁸ Thomas S. Kuhn, 'The Essential Tension: Tradition and Innovation in Scientific Research?', in *The Essential Tension: Selected Studies in Scientific Tradition and Change* (Chicago: University of Chicago Press, 1977), 225–39, p. 229.

the same topic can emphasize different approaches or subtopics; I have shown that popularizations also follow this model. As the blurb of the fifth edition of Rae's *Quantum Mechanics* emphasizes, 'The text was one of the first to include a substantial discussion of the conceptual and philosophical implications of quantum mechanics.' Rae frames these issues as properly belonging to philosophy *as well as* physics:

Inevitably many of the questions that arise in this area are matters of opinion rather than fact and, for this reason, some physicists consider that they belong more properly to the realm of philosophy than of physics. However, the conceptual basis of quantum mechanics is so fundamental to our whole understanding of the nature of the physical universe that it should surely be important for physicists to understand the nature of the problems involved, if nothing else.¹³⁹

In a footnote on the same page, he refers to *Quantum physics: illusion or reality?* as a suggestion for further reading. Notably, Rae does not argue that philosophical ideas constitute a vital component of physics, but that ideas discussed by philosophers are also worth being considered from a scientific point of view, by physicists. Physics and philosophy are presented as separate fields, but Rae creates a two-way dialogue between them. He makes the concepts from philosophy that he finds important accessible to physicists, while at the same time publishing books that open up quantum physics to non-physicists, such as philosophers, emphasizing their philosophical implications. As Rae's prefaces to the various editions show, this final chapter is the one that has undergone the most significant changes from one edition to another, with the introductions to each new edition singling out the changes to this chapter.¹⁴⁰ Such updates suggest to the reader that the conceptual problems are more cutting-edge than the mathematics.

¹³⁹ Rae, *Quantum Mechanics*, 285.

¹⁴⁰ Rae, xii–xvii. The fifth edition includes all of the prefaces to previous editions.

The connection that had been made between quantum physics and New Age mysticism after Zukav and Capra seems to have necessitated that nearly all other quantum physics popularizers explicitly distance themselves from these associations, and explain why they are wrong. Cox and Forshaw open their book with a warning against mysticist misuse of quantum physics:

Extrasensory perception, mystical healing, vibrating bracelets to protect us from radiation and who-knows-what-else are regularly smuggled into the pantheon of the possible under the cover of the word 'quantum'. This is nonsense born from a lack of clarity of thought, wishful thinking, genuine or mischievous misunderstanding, or some unfortunate combination of all of the above.¹⁴¹

Conflict narratives thus appear even in popular works that do not present an internal conflict within quantum physics; instead, this conflict is presented as one of physicists versus those who would abuse quantum physics.

One apparent exception, however, is McEvoy and Zarate. Even though their popularization is aimed at people with a strong background in mathematics, this book makes a direct link between paranormal phenomena and quantum physics: 'The only popular examples of non-locality which immediately come to mind are the voodoo interaction of Haitian-African folklore, and perhaps extra-sensory perception.' Further on, they write, 'Can we live with the preposterous concept of **action-at-a-distance** (voodoo, ESP, etc)?'¹⁴² At first sight, this seems to be an unusual approach for a popularization. ESP in particular has been widely attacked by other quantum physics popularizers, such as Gribbin: 'The people who suggest that quantum theory offers a key to practical ESP, telepathy, and all the rest are only deluding themselves.'¹⁴³ However,

¹⁴¹ Cox and Forshaw, *The Quantum Universe*, 4.

¹⁴² McEvoy and Zarate, *Quantum Theory: A Graphic Guide*, 170. Bold in original.

¹⁴³ Gribbin, *In Search of Schrödinger's Cat*, 319.

McEvoy and Zarate are not entirely serious in their apparent endorsement of the supernatural aspects of quantum physics. Instead, they assume that the reader agrees that these supernatural concepts are not real, and through suggesting that nonlocality and action-at-a-distance are just as preposterous as ESP and voodoo, they criticize those concepts of quantum physics they do not find satisfactory.¹⁴⁴

Conclusion

Scientific conflict is at the heart of quantum physics, but is not univocally expressed as such in every expository context. Authors of popular quantum physics books frame their narratives based on three parameters: their assumptions about their audience's knowledge and interests; their own personal preferences and opinions with regard to topics that are as yet unresolved; and the ways in which they do and do not want to be associated with previous publications. These three parameters are ostensibly at odds with the idea of science as presenting 'truth' or at least a consensus among experts: several authors go against the views of the scientific majority when they popularize the many-worlds interpretation in favour of the Copenhagen interpretation.

The chronology of quantum physics publications shows how changing attitudes towards philosophy in particular have influenced the content of textbooks and popular books in very similar ways. Although many of the famous quantum physicists of the early twentieth century turned toward philosophy later on in their careers, the dislike for philosophy that emerged in the late twentieth century, mostly due to the conflation

¹⁴⁴ McEvoy and Zarate's problematic framing of voodoo as 'Haitian-African folklore' rather than the syncretic religion it is, and their equation of voodoo with ESP, suggests an implied reader who is probably white, and equally ignorant and/or dismissive of this religion.

of philosophy and mysticism in some less scientific popularizations, together created a turn away from cognitive implications in nearly all popularizations. Most popular books about quantum physics, aside from the semipopular works, construct a scientific story without using mathematics or philosophy. At the same time, authors are compelled to make sure that they do not reinforce the associations with mysticism, an issue which arises particularly when including theories about which there is no scientific certainty yet.

It is not surprising that readers learn different things about quantum physics based on which popularization they read. Yet what is striking is the fact that readers learn different definitions of what quantum physics *is*, based on what they read. Contrary to many other scientific fields, quantum physics, due to its abstract and mostly theoretical nature, is particularly dependent on interpretations, which tend to conflict. The conflicting interpretations of quantum physics are negotiated differently by popularizers: some write narratives of conflict, others write narratives that show agreement among a majority of scientists. Authors such as Rae and Gribbin clearly explain to the reader that various interpretations have been found out of which they prefer one, while other popularizers, such as Cox and Forshaw, deny the reader access to this conflict, presenting only one side of it as the correct interpretation. Textbooks side with the latter option. Surprisingly, therefore, it is possible for a reader to be introduced to a conflict in science in an informal setting, only to have this conflict side-lined when the reader advances to a formal university setting; this reader will then encounter the conflict once again if she chooses to advance to a specialization in quantum physics.

Chapter Two: 'Nerd-On-Nerd Violence'

Negotiating Conflict in Physics Popularizations

Introduction

Popular science books often reach thousands more readers than scientific papers published in academic journals. The potential of these books to influence public opinion in times of scientific crisis entices some authors to write popularizations that are 'wielded as a weapon in moments of conflict between hostile factions within the scientific community.'¹ As the previous chapter showed, popularizers of quantum physics must negotiate an ongoing conflict concerning the validity of various interpretations of quantum physics. Such authors either choose to engage with the conflict by expressing their preference for one interpretation, or avoid the conflict by presenting their preferred interpretation as the only one in existence. Narratives that negotiate such a conflict, which I shall call 'conflict narratives', can help the author's chosen theory to gain a wider foothold in society, and can influence the general public's perception of science. However, studies have indicated that lay readers find it concerning to encounter conflict between scientific experts.² The popular exposition of a conflict in science could increase a reader's scepticism toward the epistemological status of science.

This chapter takes as its case study two major conflicts in physics which were communicated to the public in narratives in which the authors explicitly denounced

¹ Terry Shinn and Richard Whitley, 'Editorial Preface', in *Expository Science: Forms and Functions of Popularisation* (Dordrecht: D. Reidel Publishing Company, 1985), vii–xi, p. ix.

² Rainer Bromme, Eva Thomm, and Veronika Wolf, 'From Understanding to Deference: Laypersons' and Medical Students' Views on Conflicts Within Medicine', *International Journal of Science Education, Part B* 5, no. 1 (2 January 2015): 68–91, <https://doi.org/10.1080/21548455.2013.849017>. Since this research concerned conflicts in medicine, the concern evoked by these conflicts is likely to be more severe than that evoked by conflicts in quantum physics.

their opponents. The oldest of these two conflicts concerns the origin of the universe, debated in Cambridge astrophysicist Fred Hoyle's lecture series and book *The Nature of the Universe* (1950) and Soviet-born US astrophysicist George Gamow's book series *Mr Tompkins* (1939-1967); astrophysics has now reached a consensus on this topic in favour of the big bang theory. The second case study addresses the ongoing conflict surrounding the black hole information paradox, focusing on contemporary British astrophysicist Stephen Hawking's *A Brief History of Time* (1988) and US astrophysicist Leonard Susskind's *The Black Hole War* (2008).

Though conflict is common in science, most popularizations do not negotiate conflicts: Fahnestock claims that 'scientific accommodations [i.e. popularizations] are overwhelmingly epideictic; their main purpose is to celebrate rather than to validate.'³ Yet there have been precedents of scientists bringing their intellectual conflicts out into the public sphere: James D. Watson's *The Double Helix* is probably the most notorious example of a contemporary conflict narrative.⁴ In physics, one of the oldest and best-known conflicts is that between Newton and Leibniz concerning the development of calculus; and in 1935 the famous physicist and popularizer Arthur Eddington publicly denounced his junior colleague Subrahmanyan Chandrasekhar and his theories concerning black holes, which led to long-lasting damage to Chandrasekhar's reputation.⁵ Both of these conflicts were made public by means of short communications: lectures, articles, and letters; the authors discussed in this chapter, on the other hand, publicized

³ Jeanne Fahnestock, 'Accommodating Science: The Rhetorical Life of Scientific Facts', in *The Literature of Science: Perspectives on Popular Scientific Writing*, ed. Murdo William McRae (Athens, GA: University of Georgia Press, 1993), 17–36, p. 20.

⁴ James D. Watson, *The Double Helix: A Personal Account of the Discovery of the Structure of DNA*, ed. Gunther S. Stent, New critical ed. (1968; repr., London: Weidenfeld & Nicolson, 1981).

⁵ A. Rupert Hall, *Philosophers at War: The Quarrel between Newton and Leibniz* (Cambridge: Cambridge University Press, 1980); Arthur I. Miller, *Empire of the Stars: Friendship, Obsession and Betrayal in the Quest for Black Holes* (London: Little, Brown, 2005).

their conflicts in books. The books combine factual explanations of cutting-edge physics theories with narrative techniques that appeal to the reader's emotions. The combination of these approaches is used to encourage the reader to understand both what the author's personal contribution to the scientific field is, and why his opponents are wrong.

Conflict narratives make frequent use of embodiment to present a personal narrative. Popular science books often employ their own, the reader's, and other people's physical human bodies to affectively engage the reader. Scales much larger or smaller than the human mind can comprehend can be made more accessible by invoking human bodies, which enables the writer to appeal to the reader's personal experience; the previous chapter showed Chad Orzel's dialogues with his dog Emmy as one of the more unusual forms of embodiment.⁶ The authors discussed here present themselves as passionate, engaged people as well as scientific professionals. The scientists they disagree with are made physically present in the works through illustrations, biographies, or dialogue. By involving identified people in the argument, popular science writing breaks what is considered to be the most important rule in specialist scientific writing: the exclusion of subjectivity. As Foucault observes, from the eighteenth century onwards science has been expected and assumed to be authorless: 'Scientific discourses began to be received for themselves, in the anonymity of an established or always redemonstrable truth; their membership in a systematic ensemble, and not the reference to the individual who produced them, stood as their guarantee.'⁷ The rule that scientific papers must be written in the passive voice suggests that the writer is

⁶ Orzel, *How to Teach Quantum Physics to Your Dog*.

⁷ Michel Foucault, 'What Is an Author?', in *The Foucault Reader*, ed. Paul Rabinow (New York: Pantheon Books, 1984), 101–20, p. 109.

merely an empty vessel typing up observations.⁸ Specialist science writing is thus a paradoxical mode of writing, as Latour and Woolgar note: ‘the function of literary inscription is the successful persuasion of readers, but the readers are only fully convinced when all sources of persuasion seem to have disappeared.’⁹ Conversely, the conflict narrative aims to persuade by keeping the sources of persuasion in full sight of the reader.

The works discussed in this chapter differ from each other in three fundamental ways, the first and most obvious being the disagreement concerning a scientific fact. A discussion about facts in science must come with the caveat that current philosophers and historians of science generally agree that science is a social activity, in which the concept of a ‘fact’ is debatable: a ‘fact’ cannot always be distinguished from interpretation. Latour, as an anthropologist, makes the fairly radical claim that it is not possible to ‘distinguish “belief” from “knowledge”’, and that it is therefore not possible to isolate objective facts in science.¹⁰ Feyerabend takes an extreme view regarding the role of facts in science, arguing that ‘science knows no “bare facts” at all [...] the “facts” that enter our knowledge are already viewed in a certain way and are, therefore, essentially ideational.’¹¹

⁸ In the twenty-first century, this practice is becoming less common, as science journal editors increasingly prefer the active over the passive voice for clarity. For instance, ‘Nature journals prefer authors to write in the active voice’. ‘Writing for a Nature Journal’, *Nature*, accessed 3 August 2017, https://www.nature.com/authors/author_resources/how_write.html.

⁹ Bruno Latour and Steve Woolgar, *Laboratory Life: The Social Construction of Scientific Facts* (Beverly Hills: Sage Publications, 1979), 76.

¹⁰ Bruno Latour, *The Pasteurization of France*, trans. Alan Sheridan and John Law (Cambridge, MA: Harvard University Press, 1993), 46.

¹¹ Paul Feyerabend, *Against Method: Outline of an Anarchistic Theory of Knowledge* (London: NLB, 1975), 19.

However, many scientists do believe that there are incontestable facts; in their popularizations, they attempt to convey to the reader that such facts have been objectively established by (their own) scientific research. Through using framing methods that are not permitted in traditional scientific writing, such as leaving out the mathematical proofs, popularizers can present their viewpoints as undisputed facts to their readers. Paradoxically, the four authors discussed here use a subjective approach to convince their reader that their interpretation of the structure of the universe is the only correct, factual one. While presenting their own findings as facts and attempting to make the reader accept them as 'true', they also undermine the concepts their colleagues presented as factual, thus emphasizing the unstable position of 'facts' within science.

The second difference between the works discussed lies in their authors' attitudes towards the philosophy of science. Gamow disregards philosophy entirely, as discussed in the previous chapter. Hawking and Hoyle describe science as a Popperian, cumulative development from the ancient Greeks onwards. Susskind, on the other hand, adheres to a Kuhnian philosophy of science, in which scientific inquiry is characterized by 'the successive transition from one paradigm to another via revolution.'¹² The philosophy each author adheres to supports the point he is trying to make in his work: either that his work fits into a linear tradition of successful scientists, or that his work constitutes a revolution that overthrows the incorrect assumptions made by his predecessors.

¹² Thomas S. Kuhn, *The Structure of Scientific Revolutions*, 1962. 50th anniversary ed. (Chicago: The University of Chicago Press, 2012), 12; Susskind, *The Black Hole War*, 263–64.

The third difference concerns the authors' targeted audience and their assumptions about this audience's stance towards mathematics. As Alice Jenkins points out, from the nineteenth century onwards science relied increasingly heavily on mathematics, slowly overtaking 'the use of an English which, although specialized, was accessible to most general readers.'¹³ Whereas Charles Darwin was able to write for both an expert audience and the wider public at once, in the twentieth century the mathematization of the physical sciences complicated such an approach. In the conflicts discussed in this chapter, the adversaries in both cases have different views on the inclusion of mathematical equations in their popular work.

The Origin of the Universe:

Fred Hoyle and George Gamow

Sir Fred Hoyle (1915-2001) was an astrophysicist and science fiction author best known within the scientific community for developing the theory of stellar nucleosynthesis.¹⁴ To the general public he was famous for his denunciation of the big bang theory. In the mid-twentieth century, the astrophysics field was roughly divided into two rival camps. One side, which included Hoyle, supported the 'steady state' theory, which argued that the universe had no beginning or end, but maintained the same state and density forever. The recently discovered expansion of the universe was explained by claiming that new galaxies could appear out of nothing. The opposition, which included George Gamow, favoured a theory which proposed that the universe had a dense and

¹³ Alice Jenkins, *Space and the 'March of Mind': Literature and the Physical Sciences in Britain, 1815-1850* (Oxford: Oxford University Press, 2007), 9.

¹⁴ F. Hoyle, 'The Synthesis of the Elements from Hydrogen', *Monthly Notices of the Royal Astronomical Society* 106, no. 5 (1946): 343-383, <https://doi.org/10.1093/mnras/106.5.343>.

hot beginning and expanded from there, an idea which Stephen Hawking would later develop in a comparison to the singularities in black holes. Gamow published this theory together with his student Ralph Alpher on 1 April 1948 in a letter which is now known as the ‘Alpher-Bethe-Gamow’ or $\alpha\beta\gamma$ paper;¹⁵ Bethe’s name was added as a joke to make the alphabet pun complete.¹⁶

The steady-state theory Hoyle advocated in its stead was adhered to by a very small minority within the physics community. Ferreira claims that the public did not realize how unpopular the theory was among peers because of Hoyle’s relentless public engagement: ‘Hoyle and his two collaborators, Hermann Bondi and Thomas Gold, were a group of mavericks distorting the public’s perception of what was really going on in theoretical physics, which deeply angered their colleagues.’¹⁷ However, Hoyle was more respected in the scientific community than Ferreira’s claim suggests: more than a decade after these lectures, Stephen Hawking applied to have Hoyle as his PhD supervisor, but was assigned Dennis Sciama instead as Hoyle could not take on any more supervisees. Hawking explains that in retrospect, this was a much better arrangement: ‘the final nail in the coffin of the steady-state theory came in 1965 [...] It was just as well I hadn’t been a student of Hoyle’s, because I would have had to defend the steady-state theory.’¹⁸ White and Gribbin, in their biography of Stephen Hawking, argue that Hoyle had built up his public image simply to acquire funding, which is a not unusual reason for scientists to write popularizations:

¹⁵ R. A. Alpher, H. Bethe, and G. Gamow, ‘The Origin of Chemical Elements’, *Phys. Rev.* 73, no. 7 (April 1948): 803–804, <https://doi.org/10.1103/PhysRev.73.803>.

¹⁶ John Gribbin, *Science: A History* (London: Penguin Books, 2002), 601.

¹⁷ Pedro Ferreira, *The Perfect Theory: A Century of Geniuses and the Battle over General Relativity* (London: Little, Brown and Company, 2014), 86.

¹⁸ Stephen Hawking, *My Brief History* (London: Bantam Press, 2013), 41, 60–61.

An inveterate self-publicist, he was very good at manipulating the media and was of the breed of scientist who would on occasion publicly express unrefereed and unverified theories. His justification for this was simple. He was not an ego-maniac or intellectual cowboy, but to acquire funds for his research he needed to make a public splash, to be internationally famous.¹⁹

White and Gribbin do not explain whether they consider the steady-state theory to be ‘unrefereed and unverified’, but further on they explain that at the time it was ‘simply the more scientifically evolved of two contending theories.’²⁰ Before 1965, there was not enough observational evidence for its rival theory yet. The steady-state theory, meanwhile, was refereed: Hoyle, Gold, and Bondi published several papers on the steady state in the journal *Monthly Notices of the Royal Astronomical Society* from 1948 onwards.²¹ The discovery of the microwave radiation background in 1965 caused the steady state theory to be entirely abandoned, as cosmologists favoured its rival theory – which had by then become known under the derisive name Hoyle had given it.

Hoyle famously coined the term ‘big bang’ for Gamow’s theory because it sounded ridiculous and unscientific to him, in the radio lectures that turned him into a public figure: the BBC series *The Nature of the Universe* (1950). The lectures were subsequently published as an essay collection under the same title. These lectures were commissioned by the BBC ‘to describe the changes that have taken place in cosmology of the last ten years or so.’ Hoyle emphasized that he would therefore have to discuss ‘various issues that are still controversial.’²² Surprisingly, he does not count the big bang theory among these issues. Instead, at the moment when he gives the theory its name, he is shrugging it off as an oddity from the past:

¹⁹ White and Gribbin, *Stephen Hawking*, 71.

²⁰ White and Gribbin, 72.

²¹ Hermann Bondi, Thomas Gold, and Fred Hoyle, ‘Origins of Steady-State Theory’, *Nature* 373, no. 6509 (1995): 10, <https://doi.org/10.1038/373010b0>.

²² Hoyle, *The Nature of the Universe*, 1950, 2.

Broadly speaking, the older ideas fall into two groups. One was that the Universe started its life a finite time ago in a single huge explosion, and that the present expansion is a relic of the violence of this explosion. This big bang idea seemed to me to be unsatisfactory even before detailed examination showed that it leads to serious difficulties.²³

At several points in his lecture, Hoyle explains that the steady-state theory is a newer theory that is more valid, implying that this conflict had already been resolved in favour of the model of the steady-state theory.²⁴

Hoyle's rival George Gamow (1904-1968) was a noted astrophysicist and science popularizer based in the United States. Born in the Russian Empire and trained as an astrophysicist, he published his first popularization, in English, at the end of a period which had seen a proliferation of popular expositions of relativity in particular. Gamow's *Mr Tompkins in Wonderland, or stories of c, G, and h* (1939), illustrated by John Hookham, was a collection of stories first published in 1938-1939 in the popular science magazine *Discovery*, edited by C.P. Snow.²⁵ This work became the first instalment in the four-part Mr Tompkins series for which Gamow is most famous. Subsequent works were illustrated by Gamow himself: *Mr Tompkins explores the atom* (1944), *Mr Tompkins learns the facts of life* (1953) and *Mr Tompkins inside himself: Adventures in the new biology* (1967), the latter co-authored with Martynas Ycas. *Mr Tompkins in paperback* appeared in 1965, which collated the first two Mr Tompkins books and updated them with new material.

²³ Hoyle, 102.

²⁴ Hoyle, 102, 103-4, 105.

²⁵ George Gamow, 'Dream I: Toy Universe', *Discovery* I, no. 9 (December 1938): 431-39; George Gamow, 'Dream II: The Quantum Room', *Discovery* II, no. 10 (January 1939): 24-28; George Gamow, 'Dream III: City Speed Limit', *Discovery* II, no. 11 (February 1939): 63-68; George Gamow, 'Dream IV: More Uncertainty', *Discovery* II, no. 12 (March 1939): 134-41; George Gamow, 'Dream V: Mr Tompkins Takes a Holiday', *Discovery* II, no. 13 (April 1939): 175-80; George Gamow, 'Dream VI: Last Adventure', *Discovery* II, no. 14 (May 1939): 230-35.

Gamow created a popular science Everyman: Mr Tompkins outlived his author. Mr Tompkins's success after Gamow's death led to a reprint of *Mr Tompkins in paperback* in 1993 with an introduction by Roger Penrose, who explained the book's continuing relevance: 'Though physics has moved on in many ways, the basic physics of relativity and quantum theory has not changed.'²⁶ The series has inspired several posthumous derivative works. In 1999, Russell Stannard updated and expanded *Mr Tompkins in paperback* as *The NEW World of Mr Tompkins*.²⁷ More recently, Gamow's son Igor Gamow has created new a series of Mr Tompkins graphic novels and videos (2009-2017), illustrated by Scorpio Steele.²⁸ These remakes and updates reinforce the status of Gamow and his original popularizations as authoritative and worthy of imitation; as we will see below, the derivative works help to keep Gamow's conflict narrative in the public eye.

Gamow's protagonist is the amiable bank clerk c. G. h. Tompkins.²⁹ In what Gamow described as a 'scientifically fantastic story (not a science fiction story),'³⁰ Mr Tompkins attends physics lectures he doesn't quite understand, but at night he dreams about them. In each dream, he enters a world in which the value of a physical constant,

²⁶ Roger Penrose, 'Foreword', in *Mr Tompkins in Paperback* (Cambridge: Cambridge University Press, 1994), ix-x, p. ix.

²⁷ George Gamow and Russell Stannard, *The NEW World of Mr. Tompkins* (Cambridge: Cambridge University Press, 1999).

²⁸ The ten volumes were published in an omnibus edition in 2017: Igor Gamow, *The Complete Adventures of Mr. Tompkins* (CreateSpace Independent Publishing Platform, 2017). The accompanying website with the video versions of each story, www.theadventuresofmrtompkins.com, ceased functioning in 2014.

²⁹ His initials, c, G, and h, stand for the three most important physical constants: the speed of light, the gravitational constant, and Planck's constant.

³⁰ Gamow, *Mr Tompkins in Paperback*, xi. In the next chapter, I discuss Gamow's motivations for the explicit rejection of the science fiction label.

such as the Planck constant h , is 'so strongly exaggerated that they could be easily observed as the events of ordinary life.'³¹ The dream chapters are followed by more theoretical chapters that describe the physics lectures Mr Tompkins attended. Through his embodied encounter with forces and particles, it becomes easier for him, and hence for the reader, to understand these concepts. The lecture chapters are thus made more accessible: the reader is first introduced to the concepts and then to the underlying theory. Gamow's reviewers much appreciated this approach: J. A. Crowther's 1940 *Nature* review of *Mr Tompkins in Wonderland* notes enthusiastically that 'in a world where popular expositions of the ideas of modern physics have been almost as plentiful as blackberries, Prof. Gamow has hit on something quite novel.' He emphasizes the cutting-edge nature of the science Gamow addresses: 'The "dreams" collected in this volume first appeared in the pages of *Discovery*, and it is interesting to note how, even during the course of their publication, the outlook of modern physics changed.'³² In the final instalment in *Discovery*, for instance, Gamow lets his physics professor refer to recently published findings: 'just a few weeks ago I read an article in *Nature*, in which two young physicists suggest that [...] the universe is actually infinite'.³³ Gamow soon turned to using the Mr Tompkins books to inform his readers specifically of developments in his own, then still contested, field of the origins of the universe.

³¹ Gamow, *Mr Tompkins in Wonderland*, ix.

³² J. A. Crowther, 'Fun and Physics', *Nature* 145, no. 3676 (13 April 1940): 567, <https://doi.org/10.1038/145567a0>.

³³ Gamow, 'Dream VI: Last Adventure', p. 233.

In *Mr Tompkins in Wonderland* Gamow introduces the concepts of the big bang and the big crunch, the projected end of the universe, without commenting on alternative interpretations.³⁴ However, in *Mr Tompkins in paperback*, Gamow directly criticizes Hoyle, presumably partly as a response to Hoyle's lectures that were given after the publication of the first two Mr Tompkins books. In *Mr Tompkins in Wonderland*, the physics professor who gives the sleep-inducing lectures explains the concepts of the big bang and the big crunch to Mr Tompkins. In the next chapter, Mr Tompkins and his wife, the professor's daughter, go to the opera, and here, too, Mr Tompkins falls asleep. He dreams of a 'Cosmic Opera' about the origin of the universe. The arias, to be sung to well-known tunes, are printed in the book, including sheet music. The singers in this 'opera' are three real scientists. The first is Lemaître, a proponent of the big bang theory. The second is 'a Russian physicist, George Gamow, who had been taking his vacation in the United States for the last three decades,' who sings 'gaily and drunkenly':

Starrs will burrn to final spark,
Till our univerrse is thinnink
And is lifeless, cold and darrk.³⁵

Mockingly depicting a strong Russian accent, Gamow introduces the big bang theory by connecting it to an older concept the reader might already be familiar with: entropy, which will eventually lead to the heat death of the universe. Gamow is followed by another singer whose song is more triumphant, but not connected to familiar science. He sings to the tune of *Rule, Britannia*:

The universe, by Heaven's decree,
Was never formed in time gone by,
But is, has been, shall ever be—
For so say Bondi, Gold and I.

³⁴ Gamow, *Mr Tompkins in Wonderland*, 10.

³⁵ Gamow, *Mr Tompkins in Paperback*, 58–60.

Stay, O Cosmos, O Cosmos, stay the same!
 We the Steady State proclaim!³⁶

He appeals to Heaven, rather than to an existing scientific concept. It is clear that this singer, who is presented as the author of the opera, is Fred Hoyle: a connection is made with Cambridge and his colleagues Bondi and Gold, though Hoyle's name is never mentioned. By suggesting that Hoyle wrote the opera, and mocking himself, Gamow emphasizes the jocular aspect of the opera and avoids any accusations of defamation. However, he makes it clear to his readers that they should believe the comic character who presented a more down-to-earth idea: the professor had already explained the big bang theory in the previous chapter in a more serious setting. In the chapter following the opera visit, the professor introduces Martin Ryle's 1965 observations in radio astronomy, which suggested that the universe was expanding. His explanation is followed by a poem which describes an argument between Ryle and Hoyle, who indeed frequently clashed with each other in Cambridge:

'Your years of toil,'
 Said Ryle to Hoyle,
 'Are wasted years, believe me.
 The steady state
 Is out of date
 Unless my eyes deceive me,

My telescope
 Has dashed your hope;
 Your tenets are refuted.
 Let me be terse:
 Our universe
 Grows daily more diluted!³⁷

³⁶ Gamow, 61.

³⁷ Gamow, 63.

In a footnote, Gamow writes that Hoyle had admitted ‘a fortnight before the publication date of the first printing of this book’ that the universe was denser in the past. In an argument that deliberately juxtaposes science and art, he explains why the book still contained the opera that ridiculed Hoyle: ‘The author has decided, however, not to change the lines of the arias of “Cosmic Opera” since, once written, operas become classic.’³⁸ Russell Stannard, who mentions explicitly that the singer was intended to be Hoyle, kept the now entirely dated conflict in his 1999 revision for the same reason:

The subject of the opera – the rivalry between the Big Bang theory and the Steady State theory – can hardly be regarded as a live issue today, the experimental evidence having come down heavily in favour of the former. And yet the exclusion of this ingenious, joyful interlude would be a great loss.³⁹

Stannard cheekily suggests that Gamow’s artistic skill lends his conflict the status of a work of art that should be preserved for future generations. Gamow’s humour has thus made sure that readers born long after the scientific world dismissed the steady-state theory will continue to learn about this conflict. It is narrative skill as much as scientific content which has determined the popular science legacy of this conflict.

The Black Hole Information-Loss Paradox:

Stephen Hawking and Leonard Susskind

Stephen Hawking’s *A Brief History of Time: From the Big Bang to Black Holes* (1 April 1988) is probably the best-selling popular science book of the twentieth century. The book introduces non-experts to Hawking’s research, which includes a 1976 article in which he claimed that ‘part of the information about the state of the system is lost down

³⁸ Gamow, 64.

³⁹ Gamow and Stannard, *The NEW World of Mr. Tompkins*, viii.

the [black] hole.’⁴⁰ *A Brief History of Time* was an unprecedented success in the science popularization genre: in a later book, Hawking claimed that it ‘has been translated into 40 languages, and has sold over 10 million copies worldwide.’⁴¹ Elizabeth Leane notes that its impact was so unique, ‘commentators unanimously consider *A Brief History* a watershed in science popularization, and several suggest that due to the unique nature of its success it should be considered an anomaly within the recent history of the genre.’⁴² Its contents, however, are not anomalous: like Hoyle, Hawking presents his scientific theories as accepted fact, and dismisses alternative views.

Ironically, a persistent rumour about *A Brief History of Time* is that buyers often leave it unfinished.⁴³ Hawking admits that ‘I am sure this happens, though I don’t know that it is any more so than with most other serious books.’⁴⁴ Michael Rodgers argues that the book’s success had less to do with its intellectual content and more with its author, benefiting from what he calls ‘the “Hawking effect”, a public imagination captured by the thought of a brilliant mind imprisoned in a paralysed body, unravelling the secrets of the Universe.’⁴⁵ The reader is apparently drawn in by the affective response that Hawking’s disabled body evokes. Hawking is interpreted as representing the ultimate form of disembodied cognition: he is a mind that functions without a body, his mind working miracles while his body functions only in the absolutely minimal way that is necessary for him to be able to communicate.

⁴⁰ Stephen Hawking, ‘Breakdown of Predictability in Gravitational Collapse’, *Physical Review D* 14, no. 10 (15 November 1976): 2460–73, <https://doi.org/10.1103/PhysRevD.14.2460>.

⁴¹ Hawking, *My Brief History*, 97.

⁴² Leane, ‘Contemporary Popular Physics’, 77.

⁴³ Michael Rodgers, ‘The Hawking Phenomenon’, *Public Understanding of Science* 1 (1 April 1992): 234, <https://doi.org/10.1088/0963-6625/1/2/005>; Leane, *Reading Popular Physics*, 48.

⁴⁴ Hawking, *My Brief History*, 98–99.

⁴⁵ Rodgers, ‘The Hawking Phenomenon’, 232.

Hawking himself strongly disagrees with these ideas. In his autobiography *My Brief History* (2013), he writes:

Undoubtedly, the human interest story of how I have managed to be a theoretical physicist despite my disability has helped. But those who bought the book because of the human interest angle may have been disappointed, because it contains only a couple of references to my condition. The book was intended as a history of the universe, not of me.⁴⁶ This has not prevented accusations that Bantam shamefully exploited my illness and that I cooperated with this by allowing my picture to appear on the cover. In fact, under my contract I had no control over the cover.⁴⁷

Notably, Hawking does not comment on the accusations regarding Bantam's exploitation of his illness. His disability is indeed not mentioned as often in his own work as in Leonard Susskind's, as I will explain later, yet even so, *A Brief History of Time* is a book about people as much as about the universe. The book abounds with references to Hawking himself, as well as to more than a hundred other named people: notable physicists of the past. Hawking first covers the history of physics and its people, followed by his own scientific contributions, including his interpretation of entropy in black holes. His explanation does not make explicit that this interpretation created what would come to be known as the black hole information-loss paradox. He writes:

The second law of thermodynamics has a rather different status than that of other laws of science, [...] because it does not hold always, just in the vast majority of cases. [...] if one has a black hole around, there seems to be a rather easier way of violating the second law: just throw some matter with a lot of entropy, such as a box of gas, down the black hole. The total entropy of matter outside the black hole would go down.⁴⁸

⁴⁶ The second and third sentence are taken verbatim from a much earlier publication, which shows how strongly Hawking wants to emphasise this point: Stephen Hawking, *Black Holes and Baby Universes and Other Essays* (1993; repr., London: Bantam Books, 1997), 33.

⁴⁷ Hawking, *My Brief History*, 98–99.

⁴⁸ Hawking, *A Brief History of Time*, 113.

Many scientists strongly disagreed with this interpretation. Both physicists and philosophers of science preferred a theory in which the second law of thermodynamics held up: in a 1994 review article, physicist Don Page noted that the first objection was published a year after Hawking's paper.⁴⁹ Being associated with Hawking first and foremost, the paradox was initially 'vulgarly' called 'Hawking's information-loss paradox': as Belot et al. explain, describing the process as a loss of information is a loose, inexact description.⁵⁰ Nevertheless, from the twenty-first century onwards, the process was called the 'information-loss paradox' or the 'black hole information-loss paradox', the name Leonard Susskind would eventually adopt.

In 2008, Leonard Susskind published his physics popularization *The Black Hole War: My Battle with Stephen Hawking to Make the World Safe for Quantum Mechanics*. In this work, Susskind claimed he had resolved Hawking's paradox. The violent title and the use of Stephen Hawking's name look like an effective marketing technique to attain high sales figures: Hawking had communicated his conception of black holes to ten million readers, which turned him into one of the most famous physicists of the late twentieth century. Susskind would have to convince not only the academic world, but also Hawking's wider audience – or at least that portion of his audience which had actually read the book – that this interpretation was wrong. *The Black Hole War* can also be considered a less orthodox attempt to convince physicist colleagues, finding a way

⁴⁹ Don Page, 'Black Hole Information', in *Proceedings of the 5th Canadian Conference on General Relativity and Relativistic Astrophysics*, ed. R.B. Mann and R.G. McLenaghan (Singapore: World Scientific, 1993), 6, <http://arxiv.org/abs/hep-th/9305040>.

⁵⁰ G. Belot, J. Earman, and L. Ruetsche, 'The Hawking Information Loss Paradox: The Anatomy of Controversy', *The British Journal for the Philosophy of Science* 50, no. 2 (1 June 1999): 189–229, <https://doi.org/10.1093/bjps/50.2.189>, p. 190.

around Hawking's academic reputation: as explained further on in this chapter, Hawking's black hole radiation theories have been adopted in contemporary science textbooks, eclipsing alternative interpretations such as Susskind's.

Susskind opens his popular work by framing the conflict as having taken a long time to resolve, and having been resolved at the time of writing, so that the reader is aware of his dedication to the topic and his authority as a winner of the 'war'. He writes that he and Gerard 't Hooft had been trying to prove Hawking wrong for twenty years on the topic of black hole information loss. Whereas Hawking had claimed that information could be lost in a black hole, Susskind argues that such an idea would undermine all the fundamental laws of the universe as we know them. Susskind intends to convince the reader that Hawking is wrong, but in order to do so, he first has to explain all of the scientific concepts behind this controversy, introducing new concepts and changing readers' views on concepts they had previously taken for facts. As Elizabeth Leane points out, with regard to scientific popularizations, 'unlike the readers of novels, many of these readers believe that what they are reading is established fact.'⁵¹ It is necessary for Susskind to convince the reader that what Hawking presented as established fact is actually mistaken. The timing of the book, twenty years after *A Brief History of Time*, can work in Susskind's advantage as he can present his work as a result of two decades of further scientific development. However, the reader will most likely not be familiar with the new interpretations Susskind offers: he introduces string theory and the theory of the holographic universe, both of which are not universally accepted. He thus needs to explain first *what* he disagrees about with Hawking, before being able

⁵¹ Leane, 'Contemporary Popular Physics', 7.

to move on to explaining *why* he disagrees, and finally, and most importantly, why he is right.

Strikingly, in *The Black Hole War* Stephen Hawking's body, as a source for drawing affective responses from the readership, plays a more important role than in Hawking's own work. Susskind opens and closes his book with descriptions of Hawking's disability. He repeatedly mentions Hawking's physique when referring to personal meetings between the two, never failing to mention the wheelchair. Hawking's disabled body is even visually contrasted to the bodies of other scientists. The opening chapter contains an illustration representing Susskind and 't Hooft at a lecture given by Hawking. In the description of the lecture, Susskind spent a paragraph describing Hawking's wheelchair and 'disembodied computer voice.'⁵² The accompanying illustration shows three men seen from behind: two standing, and one in a wheelchair, all facing the Penrose diagram on the blackboard that is the true topic of the chapter.⁵³ Towards the end of the book, Susskind explicitly frames Hawking's increasing disability as one of the causes of the Black Hole War, using it as a form of explanation for his refusal to accept Susskind's theory. He shows that the popular view of Hawking as a disembodied cognition has its downsides, too:

By [1998], he had become a tragic figure. Fifty-six years old, no longer at the height of his intellectual powers, and almost unable to communicate, Stephen didn't get the point. I am certain that it was not because of his intellectual limitations. [...] But his physical abilities had so badly deteriorated that he was almost completely locked within his own head. [...] [H]e must have found it impossible to do the things that physicists ordinarily do to understand new, unfamiliar work.⁵⁴

⁵² Susskind, *The Black Hole War*, 21.

⁵³ Susskind, 22.

⁵⁴ Susskind, 419.

Susskind here emphasizes that science, even theoretical physics, does require embodiment: understanding is created through physical engagement. It was therefore Hawking's physical disability, and explicitly not his mental capacities, that kept him from understanding new developments in his field. In the 'Epilogue' to his book, Susskind describes how Hawking managed to catch up in the end in spite of this lack of opportunities for embodied interaction: 'Then, in a press conference in 2004, Hawking announced that he had changed his mind. His most recent investigations, Stephen said, had finally solved his own paradox.'⁵⁵ The framing of the resolution of the conflict depicts Susskind as the more skilled physicist because of his physical ability to solve the paradox more quickly.

The titles of both works demonstrate the different purposes for which they were written. Hawking seems to have targeted the largest possible audience through apparently simplifying the largest possible topic: the history of time itself, all the way from the beginning of the universe, in 'brief'. The combination of this title, the small size of the book, and the lack of equations all aim to draw in an audience looking for light reading that still exudes an intellectual air. The wordplay embedded in the 'brief' history of 'time' enhances this effect. Susskind's work, on the other hand, has a title that is made to impress the reader with the idea that this book will make *A Brief History of Time* obsolete: the much larger size of his book and Susskind's lack of equivalent fame require a different justification for the reader to want to buy it. He uses the terms 'war' and 'battle' and the stock superhero film phrase 'making the world safe', and takes the section titles of his book from Winston Churchill's *The Second World War*.⁵⁶ The use of

⁵⁵ Susskind, 444.

⁵⁶ Winston Churchill, *The Second World War* (London: Cassell, 1948).

so much militaristic language at first sight exudes the air of a parody: Susskind's reassurances that he much appreciates Hawking seem to confirm that the 'war' is not seriously hostile, and *The Black Hole War* ends with a picture of both men, taken in Chile in 2009, suggesting that the two are friends despite their scientific disagreements.⁵⁷ The term 'war' could also imply that Susskind found himself drawn into this conflict, at the cost of some personal sacrifice, in order to defend what he considered to be the greater good. The fact that Hawking admitted that he was wrong makes Susskind the victorious party in the 'war', which carries with it connotations of glory to the winner and shame to the loser; this perspective obscures the fact that the eventual resolution of the conflict was a synthesis of both men's views, as explained below.

Reviewers immediately understood Susskind's book as a genuine polemic that also happened to explain the fundamental laws of the universe in a quite accessible manner. Lev Grossman's review in *Time* reads as follows:

This is the story of a 25-year argument between physicists Susskind and Stephen Hawking over what happens to stuff that falls into a black hole. Hawking says it disappears; Susskind disagrees. You could dismiss it all as nerd-on-nerd violence, but then you'd miss out on Susskind explaining why the universe is actually a hologram. B+⁵⁸

Susskind's editors were apparently happy enough with this review to print its final sentence on the first page of the 2009 edition, further reinforcing its presentation as a public conflict, and attack on Hawking.⁵⁹

It must be pointed out here that Susskind's 'black hole war' has been a one-sided war, especially in popular science. In his scientific work, Hawking shows awareness of

⁵⁷ Susskind, *The Black Hole War*, 447.

⁵⁸ Richard Corliss, Lev Grossman, and Josh Tyrangiel, '5 Things You Need to Know About', *Time* 172, no. 3 (21 July 2008): 67. On this page, several books were reviewed, each of which was assigned a letter grade.

⁵⁹ Susskind, *The Black Hole War*, i.

Susskind's work by referencing it,⁶⁰ and criticizing consequences of a model Susskind offers – 'This is very ad hoc and introduces a naked singularity' – without making personal comments.⁶¹ Hawking never refers to Susskind in his popularizations. In his autobiography *My Brief History*, which is more about his work than about his person, he addresses the black hole information-loss paradox explicitly as something he resolved himself: 'This paradox had been argued for thirty years, without much progress, until I found what I think is its resolution. Information is not lost, but it is not returned in a useful way.'⁶² For Hawking, glossing over nearly four decades of debate concerning the paradox, the other people involved in the conflict did not contribute meaningfully to its resolution. Where Susskind opts for a public battle, Hawking chooses a more discreet silencing of his opponent, writing him out of history. These respective strategies reflect the two authors' preferred approaches to the philosophy of science: the Kuhnian conflict model and the Popperian linear model.

Popularization and the Philosophy of Science

As Elizabeth Leane points out, nearly all popularizations 'tend to reflect an idealized version of the progress of science.'⁶³ Popularizations often begin with an overview of the history of the field, which is presented as a cumulative progression toward the current state about which the author is going to write. This approach reflects Popper's

⁶⁰ Stephen Hawking, Juan Maldacena, and Andrew Strominger, 'DeSitter Entropy, Quantum Entanglement and ADS/CFT', *Journal of High Energy Physics* 2001, no. 5 (6 May 2001): 1–12, <https://doi.org/10.1088/1126-6708/2001/05/001>.

⁶¹ Stephen Hawking, 'Virtual Black Holes', *Physical Review D* 53, no. 6 (15 March 1996): 3099–3107, <https://doi.org/10.1103/PhysRevD.53.3099>.

⁶² Hawking, *My Brief History*, 73.

⁶³ Leane, 'Contemporary Popular Physics', 129.

philosophy of science, which investigates ‘the growth of knowledge’, positing an accumulative development of scientific knowledge without regression.⁶⁴ Hoyle describes the development of radio astronomy in this manner, boasting: ‘Just as a blazing bonfire is to a penny candle, so is the observational progress achieved in the last few decades to the work that came before.’⁶⁵ Popular works often open with a history of the field that highlights the discoveries and developments of individuals, an approach that, as Latour has pointed out, is too narrow: ‘When we are dealing with *scientists*, we still admire the great genius and virtue of one man and too rarely suspect the importance of the forces that made him great.’⁶⁶ When the author is a scientist, he nearly always includes his own contributions at the end of such an exposition. Hoyle emphasizes the inspiration of the solitary genius scientist as essential to the scientific process:

The procedure in all branches of physical science [...] is at root the same. It consists of two steps. The first is to guess by some sort of inspiration a set of mathematical equations. The second step is to associate the symbols used in the equations with measurable physical quantities.⁶⁷

By implying that a theory should come from inspiration which strikes before the interpretation of the observations, Hoyle assigns the individual scientist’s output much more prominence than the collaborative work that is central to both theorization and observation.

Hawking, too, adheres to this Popperian tradition. In *A Brief History of Time* he refers to Popper as a philosopher whose view of science he agrees with, even though

⁶⁴ Karl Popper, *The Logic of Scientific Discovery*, trans. Karl Popper, Julius Freed, and Lan Freed, 1959. Second English ed. (London: Routledge, 2002), xxii.

⁶⁵ Fred Hoyle, *The Nature of the Universe*, New ed. (Oxford: Basil Blackwell, 1952), 3.

⁶⁶ Latour, *The Pasteurization of France*, 14.

⁶⁷ Hoyle, *The Nature of the Universe*, 1952, 5.

in a later work he claims that ‘philosophy is dead’ and can bring nothing useful to science.⁶⁸ Hawking repeatedly places himself in a lineage of scientists whose impressive findings have built up only to culminate in his own work. His first chapter in *A Brief History* covers the findings of Aristotle, Copernicus, Galileo, Newton, and so on, up to the twentieth century. Einstein is discussed in a separate chapter, dedicated wholly to the development and verification of his theory of special relativity.⁶⁹ Hawking makes his own findings as the culmination of all this past research explicit: ‘As experimental and theoretical evidence mounted, it became more and more clear that the universe must have had a beginning in time, until in 1970 this was finally proved by Penrose and myself.’⁷⁰ He repeatedly mentions the fact that those who made discoveries in his field before him were rewarded with Nobel prizes – twenty-five years later, he writes that his work ‘has not so far earned me a Nobel Prize because it is very difficult to verify experimentally’.⁷¹

Hawking consistently connects scientific discoveries to a few named individuals. He argues that science can never be separated from the person behind it. Providing data that contradicts it does not automatically disprove the theory: ‘you can always question the competence of the person who carried out the observation.’⁷² Hawking teaches his readers to be critical, but also warns them that people who disagree with his theories may be wrong themselves. He thus guards himself against criticism such as Susskind’s, even if the opposition has research data that supports their arguments. Moreover, he reassures the reader that the adoption of a new theory will not lead to

⁶⁸ Hawking, *A Brief History of Time*, 11; Stephen Hawking and Leonard Mlodinow, *The Grand Design: New Answers to the Ultimate Questions of Life* (2010; repr., London: Bantam Books, 2011), 13.

⁶⁹ Hawking, *A Brief History of Time*, 2–12, 17–38.

⁷⁰ Hawking, 57.

⁷¹ Hawking, *My Brief History*, 121.

⁷² Hawking, *A Brief History of Time*, 11.

his work being disregarded entirely: 'In practice, what often happens is that a new theory is devised that is really an extension of the previous theory.'⁷³ He thus implies that his name will be remembered in the history of science even if someone finds fault with his theories, the same way Newton is remembered nowadays. Latour points out that such a temporal framework leads to a limited view of the history of science: it 'merely registers after the event the victory of certain agents.'⁷⁴ Using this framework benefits Hawking: through mentioning only the historical victories, his own work is similarly framed as a victory.

Susskind, on the other hand, cannot represent scientific development as a system in which new theories are extensions of older ones, since conflict is what led him to write *The Black Hole War*. An essential part of his narrative is the problem that no one recognized the efforts of Gerard 't Hooft and himself for twenty years. Susskind therefore explicitly adheres to Thomas Kuhn's philosophy of science, whose notions of incommensurability, revolution, and paradigm shifts as postulated in *The Structure of Scientific Revolutions* are inherent to Susskind's popularization.⁷⁵ Although conflict is also possible within a linear model, it is a central tenet of Kuhnian philosophy, which emphasizes the necessity rather than the possibility of conflict. Susskind explains Kuhn to his readers, concluding that 'Kuhn's ideas seemed right on target [...] I felt that the Black Hole War was a classic struggle for a new paradigm.'⁷⁶ The structure of his book reflects his philosophy: Susskind dedicates little space to the history of physics. Instead, he emphasizes how diverse the approaches in contemporary physics can be,

⁷³ Hawking, 12.

⁷⁴ Latour, *The Pasteurization of France*, 51.

⁷⁵ Kuhn, *The Structure of Scientific Revolutions*.

⁷⁶ Susskind, *The Black Hole War*, 263–64.

naming his colleagues, supervisors, and supervisees. Where he does mention history, Susskind speaks of clashes, giving Galileo's, Newton's, and Boltzmann's work as examples of past conflicts that have led physicists to push themselves further into new discoveries: 'At the risk of overstating the point, the greatest advances in physics have been uncovered by thought experiments that revealed a clash between deeply held principles.'⁷⁷

Like Hawking, Susskind attempts to humanize science, yet he does so in order to show that it can be flawed, because it is made by humans with imperfections such as pride, vanity and jealousy. His approach exposes the epistemic machinery of science, rather than its production of knowledge. As Karin Knorr Cetina claimed, an emphasis on the machinery rather than the final result of the scientific process 'reveals the fragmentation of contemporary science [...]. In other words, it brings out the *diversity* of epistemic cultures.'⁷⁸ Susskind explains to the reader that conflict is necessary for scientific development, thus emphasizing the importance of his work: it produces such a conflict. This reasoning follows Feyerabend's claim that science needs disagreement, anarchy and contradiction: 'Proliferation of theories is beneficial for science, while uniformity impairs its critical power.'⁷⁹ Susskind does not refer directly to Feyerabend; even if Susskind has heard of him at all, his viewpoints would be too radical for the purposes of *The Black Hole War*. First, unlike Kuhn, he does not subscribe to a theory of progress, and second, he endorses a radical inclusivity in scientific theorizing: 'There is no idea, however ancient and absurd, that is not capable of improving our

⁷⁷ Susskind, 209.

⁷⁸ Karin Knorr Cetina, *Epistemic Cultures: How the Sciences Make Knowledge* (Cambridge, MA: Harvard University Press, 1999), 3.

⁷⁹ Feyerabend, *Against Method*, 11.

knowledge.⁸⁰ Susskind, despite his conflict model, never suggests that science should be this open and radical: his own authority is never doubted in his book.

A different light is shed on the conflict narrative when over the course of the book Susskind reveals that the controversial theory he proposed was in fact a proposal for *complementarity*. The revolution turned out to be a synthesis, as Amanda Gefter explains:

When Hawking pitted [gravity and quantum mechanics] against each other, the result was the black hole information-loss paradox, which looked to be a lose-lose situation until Susskind's epiphany – *restrict to a single observer's point of view* – provided an escape.⁸¹

Hawking's theory had posited two possibilities that seemingly contradicted each other, and Susskind, comparing this situation to the wave/particle complementarity of light, suggested the theory of black hole complementarity, with which Hawking eventually agreed. Susskind takes the time to explain to his readers what a paradigm shift is, but the 'Black Hole War' did not lead to a paradigm shift in which the new theory is incommensurable with previous ideas. Susskind uses philosophy of science as a persuasive technique, bringing in Kuhn to make the conflict look revolutionary. A narrative of complementarity would not be as marketable as a conflict narrative, and would not allow Susskind to explicitly make the case that he is a better quantum physicist than Hawking.

⁸⁰ Feyerabend, 48.

⁸¹ Gefter, *Trespassing on Einstein's Lawn*, 338.

Physicist and Non-Physicist Audiences

The ideal reader for the four works discussed in this chapter is what Gillian Beer describes as an 'educated reader': 'An "educated reader" here must imply not simply a level of literacy but a level of shared cultural assumption and shared cultural controversy.'⁸² The ideal reader has not only completed secondary school, but also shares norms and values with the author, which the author targets in constructing a narrative that will interest and convince his readers. Mr Tompkins closely resembles Gamow's ideal reader: a middle-class professional man who is interested in physics in his spare time, but who has not quite enough knowledge of contemporary physics to follow a physicist's public lecture. However, Mr Tompkins is, probably deliberately, presented as slightly clumsier and more ignorant than this ideal reader: presumably, the reader would feel superior for not normally falling asleep at the opera; this sense of superiority prevents him from feeling patronized in the learning process. Women are included as a potential audience from the second volume onwards, when Mr Tompkins's wife, Maud, has an adventure of her own concerning entropy. Through disseminating the contents of their books to such a large, educated audience, authors such as Gamow were potentially able to influence public opinion on science and research. Beer points out that public opinion beyond the scientific sphere needs to be influenced before a theory takes on full validity: 'science proceeds by revolution and not by addition pure and simple. This revolution must take place not only in the minds of scientists but in the beliefs of other inhabitants of the same culture if the theory is to reach its full authority.'⁸³ As the conflict between Gamow and Hoyle shows, however, two conflicting

⁸² Beer, *Darwin's Plots*, 41.

⁸³ Beer, 1-2.

theories can be communicated to the public at the same time, years before new evidence caused one of these two to be abandoned. Newer popularizations can undo the public acceptance of a theory by making a convincing case for an alternative theory.

Whitworth argues that in a time of increased specialization, scientists, too, need popularizations to keep on top of developments that are not entirely within their field.⁸⁴ The specialization of the sciences became a growing concern from the 1920s onwards: in 1921, Richard Gregory, the President of the British Association for the Advancement of Science (BAAS), emphasised a need for people skilled at championing and advocating science.⁸⁵ As even physics itself has now branched into specialist subject areas, peers and colleagues in physics also form part of the targeted audience for the popularizations discussed here. As Leane explains, popularizations can be used to communicate theories that might not be accepted in mainstream academic publishing:

Popularizations can [...] be deliberately deployed by scientists to make others in their own discipline, or other scientific disciplines, aware of particular ideas. This is especially useful if these ideas are too speculative or unusual to find a place in professional journals. However, scientists are rarely the *primary* readership at which a popularization is aimed.⁸⁶

Hawking's biographers claim that he aimed to reach beyond an exclusively middle-class audience: 'he wanted to reach the broadest audience possible. He wanted plumbers and butchers to read his book as well as doctors, lawyers and science students.'⁸⁷

Hawking's own words were not so specific: he merely spoke of 'the general public, not just academics.'⁸⁸ However, the language and metaphors Hawking employs in his book

⁸⁴ Whitworth, *Einstein's Wake*, 31.

⁸⁵ Oliver Hill-Andrews, 'Interpreting Science: JG Crowther and the Making of Interwar British Culture' (PhD thesis, University of Sussex, 2015), 85.

⁸⁶ Leane, *Reading Popular Physics*, 11.

⁸⁷ Michael White and John Gribbin, *Stephen Hawking: A Life in Science* (London: Penguin Books, 1992), 244.

⁸⁸ qtd. in White and Gribbin, 244.

do seem to cater to academics: he speaks of what should be done ‘in order to have a reasonable chance of seeing an explosion [of a black hole] before your research grant ran out,’ assuming a shared academic frame of reference with the reader, and he explains the uniformity of the universe by comparing it to setting a group of students an exam.⁸⁹ Hawking never makes use of mathematics, which constitutes an essential part of the scientific training of formally schooled physicists, but he still assumes his readers to possess university-level information processing skills. He often explains his scientific concepts at a pace too fast for many readers to follow. As Rodgers notes, ‘a number of tough concepts which are vital for following the argument are explained at a pace which must bewilder general readers who lack a background in physics.’⁹⁰

Susskind attempts to reduce the apparent distance between himself and his non-physicist audience by identifying himself as one of them. After having introduced the Black Hole War and the physicists involved in it on both sides, including himself, he temporarily retreats from his position as an expert physicist. He posits himself either as a neutral go-between, or as being on the side of the reader, consistently referring to physicists as third-person others: ‘The term *acceleration* refers to any change in velocity, including the slowing down that we ordinarily call deceleration. To a physicist, deceleration is merely negative acceleration.’⁹¹ Through contrasting the ‘we’ with ‘a physicist’, Susskind implies that he is mediating between the complicated world of physicists and the world he and the reader are part of. He implicitly contrasts himself – a relatable, casual man – to the inaccessibly distant high-flying physicists such as Hawking.

⁸⁹ Hawking, *A Brief History of Time*, 122, 134.

⁹⁰ Rodgers, ‘The Hawking Phenomenon’, 233.

⁹¹ Susskind, *The Black Hole War*, 65, italics in original.

Susskind does not bring his identity as a physicist up again until the lay reader understands the nature of the ‘battle’ that he has been waging with Hawking. However, throughout the work he occasionally inserts information that only a reader well versed in physics could understand, to avoid misunderstandings. In one explanatory footnote, he writes: ‘Note to the experts: The embedding diagram that follows is not in constant Schwarzschild time. It is obtained by using Kruskal coordinates and choosing the surface $T=1$.’⁹² Since Kruskal coordinates are not explained, or even mentioned, throughout the rest of the book, it is clear that this footnote is aimed at a physicist readership. The footnote makes clear that Susskind does not have a single type of ideal or implied reader in mind: his book is aimed both at expert physicists and at non-experts who do not like mathematics.

Neither Hoyle nor Gamow tailors any part of his work to potential physicist readers. Gamow might even be seen as mocking physicists: their lectures are sleep-inducing. Hoyle retreats from his position as a physicist by emphasizing the extent of specialization within physics. In his second lecture, he claims: ‘There is a difficulty for a member of the general public like myself to work out whether a hydrogen bomb can be made.’ He explains that the difficulty is due to part of the procedure not having been published.⁹³ Hoyle devotes a subchapter to this bomb, connecting a topic of contemporary significance with his own field: through a comparison with the hydrogen and atomic bombs he provides a recognizable explanation of the way in which stars work. This analogy shows how closely related nuclear physics and astronomy are, yet Hoyle considers astronomers to be different from physicists, describing physics as a closed

⁹² Susskind, 69.

⁹³ Hoyle, *The Nature of the Universe*, 1950, 43. The paragraph in which he makes this claim is removed from the 1952 edition.

community which guards the hydrogen bomb secret. Rather than identifying himself as a different kind of scientist, he uses this opportunity to strengthen his connection to the general public.

The way in which physicists respond to popular science books written by their peers is largely determined by the reputation these authors have within the physics community. Hawking's reputation as a scientist does not seem to have been at all negatively affected by the unparalleled success of his popular book. Popular science works earlier in the twentieth century were received much less enthusiastically by scientist colleagues. Whitworth explains that James Jeans and Arthur Eddington, both established scientists and best-selling popularizers of the 1920s and 30s, suffered from the scientific elitism present in their time as their popularizations were held against them.⁹⁴ Pedro Ferreira contends that the reputations of Hawking and Susskind were established enough not to be tainted by the publication of popularizations. Such negative associations, he claims, only arise if a scientist's reputation has not been established firmly enough before publication, which could lead to their becoming known as a popularizer in the first place and as a scientist only second.⁹⁵

Reviews of *A Brief History of Time* and *The Black Hole War* by fellow physicists confirmed the status of Susskind and Hawking as respected physicists, but qualified their claims with regard to the information paradox. Caltech physicist Sean Carroll wrote the most positive review of Susskind, in the *Wall Street Journal*, claiming that 'Mr. Susskind [...] is one of the pioneers of string theory [...]. He is famous within the

⁹⁴ Whitworth, *Einstein's Wake*, 20.

⁹⁵ Pedro Ferreira, Interview, Telephone, 28 January 2015.

physics community for his wit and storytelling abilities.⁹⁶ Mathematician and quantum physics lecturer Peter Woit strongly criticized Susskind's first popularization, *The Cosmic Landscape* (2005), as 'pretty much appalling,' denouncing it for 'promoting outright pseudo-science, of a sort that unfortunately has been highly influential.' He added, however, that he considered *The Black Hole War* 'about 10^{500} times better,' arguing that 'Susskind gives a good introduction to lots of topics in physics and to the black hole information paradox in particular.'⁹⁷ Physicist and popularizer Paul Davies was more generous about Susskind's reputation, pointing out in his review for *Nature* that 'Susskind has made seminal contributions' to string theory. Yet, more importantly, Davies then criticized the scientific content of Susskind's work: 'quantum gravity is still too unrefined for a rigorous proof.'⁹⁸ An interesting comparison can be made with the review Davies wrote of *A Brief History of Time*. He called Hawking 'one of the more remarkable scientists of our generation,' and although he pointed out that 'Hawking assumes that enough theoretical technology is available for some interesting conclusions to be drawn,'⁹⁹ he did not express any disagreement with Hawking's statement on black holes.

⁹⁶ Sean Carroll, 'Lost in Space', *Wall Street Journal*, 28 July 2008, sec. Leisure/Weekend, <http://www.wsj.com/articles/SB121720140527588397>.

⁹⁷ Peter Woit, 'The Black Hole War', *Not Even Wrong* (blog), 23 June 2008, <http://www.math.columbia.edu/~woit/wordpress/?p=703>.

There are about 10^{80} atoms in the universe. It is interesting to see how loosely scientific professionals can apply numbers in writing for what seems to be their peers, or at least people who are familiar with the scientific notation.

⁹⁸ Paul Davies, 'Betting on Black Holes', *Nature* 454, no. 7204 (31 July 2008): 579–80, <https://doi.org/10.1038/454579a>.

⁹⁹ Paul Davies, 'Essay Review: A Brief History of Time', *Contemporary Physics* 30, no. 2 (1 March 1989): 135–36, <https://doi.org/10.1080/00107518908225512>, p. 136, 135.

A 1988 review in *Physics Today* bestowed gushing praise upon Hawking and his work: 'Hawking is one of the leading theorists of our time' and his book 'can be recommended to any physicist who would like to know what is going on in these fields today.' The difficulty of the book for a general audience is remarked upon in an aside: '(One wonders a bit what the general reader must make of some of this material.)'.¹⁰⁰ The author reviews the work as if it is written for physicists outside Hawking's area of specialization, a far cry from White and Gribbin's 'plumbers and butchers'. The *Nature* review of Hawking's book, written by Don Page, who eight years earlier had published an objection to Hawking's approach to information loss,¹⁰¹ contains entirely different treatments of Hawking as a person and Hawking's scientific theories. The review describes him as 'the greatest gravitational theorist since Albert Einstein,' but further on, in a detailed exploration of the partially proven scientific theories described in the book, Page warns that 'Although many of these caveats are noted in the book, there is the danger that Hawking's enthusiasm for his proposal may lead the less-cautious reader to become more convinced of its correctness than there is yet evidence to warrant.'¹⁰² Page's is a minority voice even among reviewers who write for specialist physics journals and magazines when he points out that not everything in this book is commonly accepted by the physics community. This is precisely the issue Susskind addresses with his popularization: not many people have picked up on the fact that some of the theories Hawking presented as facts may be controversial, perhaps because of

¹⁰⁰ James L. Anderson, 'A Brief History of Time', *Physics Today* 41, no. 11 (November 1988): 116, 117, <https://doi.org/10.1063/1.2811637>.

¹⁰¹ Don Page, 'Is Black-Hole Evaporation Predictable?', *Physical Review Letters* 44, no. 5 (4 February 1980): 301–4, <https://doi.org/10.1103/PhysRevLett.44.301>.

¹⁰² Don Page, 'Hawking's Timely Story', *Nature* 332, no. 6166 (21 April 1988): 742.

Hawking's status among peers and the general public alike, and a wider audience must be made aware of this controversy.

Don Page also reviewed *The Black Hole War*, for *Physics Today*. While hailing Susskind as 'a father of string theory', he nevertheless emphasized, as an insider to the conflict, that Susskind's claims regarding string theory as the solution to the issue were not uncontroversial:

Susskind argues that the black hole war has been won by those who fought to save the world for quantum mechanics. Although I have generally agreed with that position for more than 29 years, and I recognize that strong reasons have been developed to support it, I would caution that theorists do not yet fully understand how information gets out of a black hole or, alternatively, avoids falling into one.¹⁰³

Page's review shows that Susskind has several fellow adversaries in the fight against Hawking's propositions, but not all of these comrades in arms agree with Susskind's proposal that string theory unambiguously resolves the conflict.

String theory is far from universally accepted. Roger Penrose, who himself is sceptical of string theory, points out that three recent popular science books condemn it even more strongly than he does.¹⁰⁴ The representation of Hawking's and Susskind's work in textbooks is an indication of their status within the wider physics community: twenty-first-century physics textbooks show that there are as yet too many uncertainties surrounding the theory to allow it in textbooks. Physics textbooks on black holes tend to acknowledge Hawking's contribution to the field, but not Susskind's. Dermer

¹⁰³ Don Page, 'The Black Hole War: My Battle with Stephen Hawking to Make the World Safe for Quantum Mechanics', *Physics Today* 62, no. 5 (4 May 2009): 57–58, <https://doi.org/10.1063/1.3141946>.

¹⁰⁴ Roger Penrose, *Fashion Faith and Fantasy in the New Physics of the Universe* (Princeton, NJ: Princeton University Press, 2016), 1; Peter Woit, *Not Even Wrong: The Failure of String Theory and the Continuing Challenge to Unify the Laws of Physics* (London: Jonathan Cape, 2006); Lee Smolin, *The Trouble with Physics: The Rise of String Theory, the Fall of a Science, and What Comes Next* (Boston: Houghton Mifflin, 2006); Jim Baggott, *Farewell to Reality: How Fairytale Physics Betrays the Search for Scientific Truth* (London: Constable, 2013).

and Menon explain the concept of Hawking radiation, and acknowledge its limits: when the option of ‘Hawking radiation from low-mass, evaporating black holes’ is mentioned, they explain that ‘no evidence for evaporating black holes was found [...] and it would be a great but unexpected discovery for the Fermi Gamma Ray Space Telescope to detect evaporating black holes.’¹⁰⁵ In their book, they do not touch upon the string theory alternative, however, and Susskind and the information-loss paradox are never mentioned. Frolov and Zelnikov do mention the information-loss paradox in their textbook, which is aimed at ‘graduate students, postdocs, and young researchers,’ acknowledging that string theory presents an alternative interpretation, but they conclude that ‘Unfortunately, these and some other results of string theory essentially rely on the use of supersymmetry, the property that is apparently violated in our real world, at least at the present time.’¹⁰⁶ Susskind is not mentioned in this book either, which indicates that Susskind’s individual contribution to physics is considered of less importance in recent specialist textbooks than Hawking’s. It seems that Susskind was attempting to convince non-experts before his own peers were entirely convinced, whereas the opposite seems to have been true for Hawking; at the same time, even if Susskind’s non-expert audience did not accept his alternative views, his book was able to show that Hawking’s views are not the only ones current among physicists, nor are they endorsed by everyone.

¹⁰⁵ Charles D. Dermer and Govind Menon, *High Energy Radiation from Black Holes: Gamma Rays, Cosmic Rays, and Neutrinos*. (Princeton, NJ: Princeton University Press, 2009), 452.

¹⁰⁶ Valeri P. Frolov and Andrei Zelnikov, *Introduction to Black Hole Physics* (Oxford: Oxford University Press, 2011), vii, 45. Their use of the phrase ‘the present time’ can be taken to have quite a broad meaning: current theories point to the idea that the laws of physics may have been different during the period of rapid inflation, 10^{-32} seconds after the Big Bang (13.7 billion years ago).

The Role of Mathematics in Conflict Narratives

Science popularizers must decide whether to include mathematics or not in their texts. Science seems to have replaced stories with mathematical proofs, which are considered more objective. Okasha claims that Galileo first introduced this practice of replacing stories with proofs, as he insisted that his mathematical results trumped the statements given in the Bible.¹⁰⁷ However, science and its conflicts cannot be expressed in mathematics alone: as Charlotte Sleight points out, ‘these disputes are never “purely” scientific; they are always language-based processes that cannot be reduced to a non-linguistic form.’¹⁰⁸ Contemporary popularizers tend to remove the equations when explaining scientific findings to a wider audience: Leane names a ‘lack of mathematical content’ as one of the characteristics by which one can recognize a book that is written for a ‘lay readership.’¹⁰⁹ However, leaving mathematics out entirely is a relatively recent development. Gamow includes mathematics in the lecture parts of his *Mr Tompkins* books: *Mr Tompkins in Wonderland*, for example, contains twenty equations and two matrices.

Price argues that leaving out mathematics entirely creates an impasse between ‘elite knowledge owners’ and those readers who have no access to mathematics, reinforcing the divide between those with and those without a scientific education.¹¹⁰ As discussed in the previous chapter, many contemporary popularizers mention how important mathematics is for a full understanding of quantum physics, making the reader

¹⁰⁷ Samir Okasha, *Philosophy of Science: A Very Short Introduction* (Oxford: Oxford University Press, 2002), 5.

¹⁰⁸ Sleight, *Literature and Science*, 4.

¹⁰⁹ Leane, *Reading Popular Physics*, 11.

¹¹⁰ Price, *Loving Faster than Light*, 56.

aware that, because of their educational background, they will not fully understand the material even after having finished the book.

Authors and editors of popular science books frequently express the belief that nearly all readers have a natural aversion to mathematics. Hoyle describes how he was told not to use mathematics, possibly due to the aural nature of his radio lectures: 'it is necessary to go deeply into the mathematical investigations if [the arguments'] real force is to be fully appreciated, and this is just what the B.B.C. has conjured me [*sic*] not to do.'¹¹¹ As a compromise, he gives one mathematical problem, invented by Eddington, in his book. This problem, Hoyle writes, 'is specially remarkable, for although it needs considerable analytical power to solve it, yet no more actual mathematics is involved than is possessed by the average child of ten.'¹¹² He thus challenges his readers intellectually without demanding that they first master mathematics beyond what they can be assumed to know already. Even so, this section was removed from the 1952 edition of the book, leaving that work entirely devoid of mathematics.

As mentioned in the previous chapter, Hawking famously wrote in the introduction to *A Brief History of Time* that he 'resolved not to have any equations at all.'¹¹³ He made only one concession: 'In the end, however, I *did* put in one equation, Einstein's famous equation, $E=mc^2$. I hope that this will not scare off half of my potential readers.'¹¹⁴ This equation appears several times, and is explained at length when it makes its first appearance; the explanation takes up a full page. Hawking does not use a similar approach for other, more easily understood, equations. For instance, he describes

¹¹¹ Hoyle, *The Nature of the Universe*, 1950, 6.

¹¹² Hoyle, 6.

¹¹³ Hawking, *A Brief History of Time*, ix.

¹¹⁴ Hawking, ix.

Newton's theory of gravity without mentioning equations: 'bodies attracted each other with a force that was proportional to a quantity called their mass and inversely proportional to the square of the distance between them.'¹¹⁵ Here he has verbally articulated the inverse square law, $F = \frac{GMm}{r^2}$, without having mentioned the equation itself. The reader is not given the option to discover that equations, which can look frightening at first, may be quite understandable. A diligent student of Hawking's book could have understood the contents of the inverse square law as presented here, but would not be able to recognize it in a formal scientific context.

In a later work, Hawking expressed a dislike for equations which no doubt made it easier for him to concede to their omission in his popular texts:

I don't care much for equations myself. This is partly because it is difficult for me to write them down, but mainly because I don't have an intuitive feeling for equations. Instead, I think in pictorial terms, and my aim in the book was to describe these mental images in words, with the help of familiar analogies and a few diagrams.¹¹⁶

Equations are indeed remarkably scarce in some of Hawking's scientific papers, including the paper that originally led to the information-loss paradox.¹¹⁷ However, leaving out equations can hardly be considered a mindset that generally informs his work, as other, much more equation-heavy, publications show.¹¹⁸ One possible justification for this absence of mathematics in *A Brief History of Time* is the economic argument that it would be easier to convince a browsing potential buyer that this book contains acces-

¹¹⁵ Hawking, 11.

¹¹⁶ Hawking, *My Brief History*, 95.

¹¹⁷ Hawking, 'Breakdown of Predictability in Gravitational Collapse'.

¹¹⁸ Stephen Hawking, 'Singularities and the Geometry of Spacetime', *The European Physical Journal H* 39, no. 4 (1 November 2014): 413–503, <https://doi.org/10.1140/epjh/e2014-50013-6>.

sible leisure reading, as Cambridge University Press editor Simon Mitton told Hawking.¹¹⁹ Skimming through the book, one would see that it contains pictures and brief textual chapters, and is short – two hundred pages, compared to Susskind’s 470. Yet a simple transposition from physics into language does not automatically create a clear, accessible popularization. A popular exposition of physics requires two levels of transposition: the mathematics need to be rewritten into words, and the theory needs to be reformulated in an accessible manner. If the latter transposition is not taken into account, the reader will still not be able to engage with a qualitative, mathematics-free account, as the readership issues surrounding *A Brief History of Time* show.

Susskind, on the other hand, has no problem whatsoever with putting equations into his book; like Rae in the previous chapter, he gives a few equations extra attention by setting them apart from the main text body in their own explanatory text box. The inverse square law mentioned above is one of these equations.¹²⁰ Susskind deliberately blurs the division between professional physicists and non-expert readers: the final section in his second chapter is meant ‘for those who enjoy a bit of math,’¹²¹ without any further specification of the qualifications or level of mathematical training these readers should have. He suggests that everyone can enjoy maths, but nobody is forced to engage with it; similarly, he implies that one does not need to be a professional physicist in order to have advanced knowledge of physics.

¹¹⁹ White and Gribbin, *Stephen Hawking*, 243.

¹²⁰ Susskind, *The Black Hole War*, 49.

¹²¹ Susskind, 47.

Susskind's approach to mathematics is part of his narrative against Hawking. He explains his method to the reader by referring to the same claim about equations that convinced Hawking *not* to include them:

When I began to write books for a general audience, I was strongly advised to keep the equations down to only one: $E = mc^2$. I was informed that for every additional equation that I included, I would sell ten thousand fewer books. Frankly, that goes against my experience. People like to be challenged: they just don't like to be bored.¹²²

This stance regarding the willingness of readers to struggle with challenging material informed his *Theoretical Minimum* works discussed in the previous chapter. In *The Black Hole War*, he uses this statement to involve the reader in the argument between Hawking and himself. The first half of his book contains many more equations than the second half: the reader is drawn into a challenge from the start, which leads one reviewer to complain, 'I was eager to learn how, in the end, Susskind and company showed that Hawking was probably wrong [...]. But first I had to get through a 66-page crash course on relativity and quantum mechanics.'¹²³ Even though the absence of equations in Hawking's book does not seem to have made it significantly easier for his audience to understand its contents, Susskind puts the reader's intelligence at stake in the conflict when he adamantly refuses to remove all equations.

Conclusion

Fred Hoyle, George Gamow, Stephen Hawking, and Leonard Susskind have written the popularizations discussed in this chapter only partially in order to educate the reader

¹²² Susskind, 151.

¹²³ George Johnson, 'The Theory That Ate the World', *The New York Times*, 22 August 2008, sec. Sunday Book Review.

about a scientific topic. They have put much care into narrative strategies to convince the reader that the author is an expert in a particular field, and most importantly, that the theory each author has helped develop is better than the one proposed by a rival scientist. However, the reader first needs to learn about the context of the conflict, which requires an exposition of scientific 'facts' before the authors can make their point, one in which conflict forms part of the development of the framework. The books thus also teach the reader about the context in which knowledge production takes place.

The authors' frequent referral to human beings and their bodily presence in the world makes the incomprehensible, abstract scales at which quantum physics and astrophysics take place more accessible, and at the same time grounds science as a profoundly human endeavour. The choice of whether or not to include mathematical equations shows what kind of engagement is expected from the readership: where Gamow and Susskind include a large number of equations, Hoyle and Hawking choose to avoid them completely, thus refusing the reader access to a scientific community which these days relies almost entirely on mathematics. Finally, their interpretation of the philosophy of science informs the way these authors teach their audience about science and its historical functioning: emphasizing conflict in science would be to Susskind's advantage, so he refers to Kuhn's philosophy which adopts this approach to scientific change. Hoyle and Hawking, for whom an emphasis on the linear development of science is beneficial to their argument, follow Popper.

Conflicts in science can be detrimental for a scientist's career, as the Eddington/Chandrasekhar conflict showed. A conflict will reduce the pool of potential collaborators, a serious hindrance to the 'Big Science' projects that have become increasingly prominent in the twenty-first century. In that respect, it is particularly notable that

conflict narratives seem to be inherently masculine. The gender dynamics of the works discussed in this chapter suggest an underlying structure of a boys' club, in which insults are exchanged, and fights occasionally break out, which yet resolve themselves quickly because there is a shared assumption of respect and reciprocal equal treatment. Susskind's insults towards Hawking as a physically disabled scientist, followed by a cheery picture of the two men at a conference, certainly seems to reinforce such assumptions. Minority groups within science, which still include women, cannot count on similar equality of treatment or the opportunity to reciprocate; conversely, an established white male scientist who insults such a minority figure may experience severe responses from people who are encouraging the scientific field to be more open and welcoming: Eddington was frequently accused of racism after his snubbing of Chandrasekhar, and James Watson has been described as using 'sexist stereotypes to obscure what should have become a scientific scandal' in *The Double Helix*.¹²⁴ In a male-dominated world, a conflict narrative between a man and a woman is likely to play out into a battle of the underdog versus the establishment, no matter which positions the two combatants actually occupy towards each other.

The personal fights discussed in this chapter affect the public perception of science and science popularizations in general. The author shapes the public perception of scientists according to his description of the individuals involved in the conflict.¹²⁵ As Leane has pointed out, 'if the public mistakenly equates individual scientists with science, and the individual scientist is then seen to be fraudulent or incorrect, then the

¹²⁴ Miller, *Empire of the Stars*, 13; Ruth Hubbard, 'Science, Power, Gender: How DNA Became the Book of Life', *Signs* 28, no. 3 (March 2003): 791–99, <https://doi.org/10.1086/345334>, p. 798.

¹²⁵ Sleight, 'Writing the Scientific Self', 19.

public loses faith in science itself.¹²⁶ If the public has come to equate Fred Hoyle or Stephen Hawking with the most advanced and difficult physics, and Gamow or Susskind prove their predecessors wrong, this may undermine the public's faith in science as a whole, as the scientific method no longer seems to be a reliable source of facts. That consequence would not necessarily be negative. Unwavering faith in an individual scientist and in all of the scientific claims he makes in his popularizations could be misplaced, and could obstruct scientific development if the eminence of one scientist leads to a lack of funding for scientists who wish to explore alternative viewpoints. A dogmatic approach to science, in which some facts are held to be self-evidently and unquestionably true, would not allow for a re-interpretation if anomalies are found. Both quantum physics and string theory came into being as seemingly unbelievable explanations for phenomena which had previously been quite well understood in a more intuitive manner, bar a few minor but bothersome exceptions. These revolutionary new theories required a complete dismissal of many concepts that were once considered absolutely fundamental to physics, such as the idea that particles should exhibit predictable, rule-bound behaviour; such theories could therefore not have arisen if the faith in the founders of classical physics, such as Newton, had been unwavering.

Conflict narratives can be controversial, but they can also teach the reader to question the information they have been given, a desirable skill in the current political climate. These narratives could prove to the reader that conflicts in science are common. Reading either set of conflicting popularizations could transform a reader's uncritical and simplistic understanding of science and show to them that science is not an

¹²⁶ Leane, 'Contemporary Popular Physics', 240.

objective process that produces facts: instead, it is a human endeavour in which conflicting opinions and personal preferences are often an essential part of scientific development.

Chapter Three: 'This is Not Science Fiction' Scientifically Fantastic Popularizations

'Any sufficiently advanced technology is indistinguishable from magic.'

Arthur C. Clarke¹

'multa secreta naturae et artis aestimantur ab indoctis magica'

Roger Bacon²

Introduction

As described in the previous chapter, science popularizations nearly always frame their contents as objective facts, even when these contents are still under debate among scientists. At the same time, however, these books do not adhere to the conventions of neutrality and objectivity that are expected of regular scientific writing. Whilst every form of science writing is to a certain extent tied to the rhetorical effects inherent in language, popularizations strive to use these effects deliberately. The possibilities for additional layers of expressiveness that language is capable of adding are often carefully explored: at the very least, analogy is used for explaining abstract concepts. Many popularizations go much further in their employment of literary techniques to teach the reader, making frequent use of metaphor; some even use an overarching metaphorical trope to sustain the narrative as a whole. Such use of rhetoric reflects a tradition in didactic literature that has been upheld for thousands of years, but is ostensibly at odds with the intentions of popularizers to deliver objective scientific content. As reliance on metaphor 'may generate meaning in excess of the accepted scientific

¹ Arthur C. Clarke, *Profiles of the Future: An Inquiry into the Limits of the Possible*, 1962. Millennium ed. (London: Indigo, 2000), 2.

² 'many secrets of nature and of art are thought by the unlearned to be magical'. Quoted and translated in Tom Shippey, 'The Golden Bough and the Incorporations of Magic in Science Fiction', in *Hard Reading: Learning from Science Fiction* (Liverpool: Liverpool University Press, 2016), 162–81, p. 162.

concepts which are the apparent content of the text,³ it is worth investigating why popularizers would want to make such frequent use of this rhetorical device.

In this chapter, I will discuss the function of metaphor, analogy, and allegory in works that present a fictional, fantastical narrative, often with a humorous or satiric element to embed the scientific contents of the text. George Gamow named this manner of writing the ‘scientifically fantastic story,’ or in a shorter form the ‘scientific fantasy,’ a term which I will continue to uphold here to provide a contrast to science fiction.⁴ The usage of this genre is reminiscent of the use of the parable in nineteenth-century didactic fiction. Gillian Beer observes of the parable:

It was often used as a satiric weapon for getting under the [...] reader’s guard, insinuating distance, and separating the group from its habitual self-image. Its humour protected the speaker from giving offence: the playfulness of the form [...] reinserted the speaker into the community from which telling the story simultaneously detached him (or, much less frequently, her).⁵

Like the parable, the scientific fantasy allows the author to renegotiate the distance between the author as scientist and the non-expert reader. As the twentieth-century successor of the parable in scientific didacticism, the scientific fantasy has been little explored in previous critical writing. The genre presents a compelling case study because of the manner in which science and fiction are blended, requiring the reader to be able to distinguish between the two.

The chapter will focus on three sets of works, which together cover a time span of more than a century. First of all, Edwin Abbott Abbott’s *Flatland, or a Romance of Many Dimensions* (1884), a story set in a two-dimensional universe, was designed both

³ Leane, ‘Contemporary Popular Physics’, 164.

⁴ Gamow, *Mr Tompkins in Paperback*, xi.

⁵ Beer, *Open Fields*, 197.

to help readers understand the concept of four physical dimensions, and to satirize Victorian norms and values.⁶ Although this work predates the period I am examining in the thesis, I have included it as it remains one of the best-known science fantasies, and established conventions for and expectations about the science fantasy genre; later re-makes of *Flatland*, including *Bolland* (1957) and *Flutterland* (2001) use Abbott's fantasy to explain contemporary mathematics and physics. The second case study, George Gamow's *Mr Tompkins* series used fictional dream worlds to be able to add a tangible element to abstract phenomena from modern physics. Abbott's and Gamow's works have in common that their combination of fantasy and science communication proved extremely successful, to such an extent that the works were re-written around the turn of the twenty-first century by eminent contemporary scientist-popularizers, in order to incorporate the latest developments in science. Mathematician Ian Stewart rewrote *Flatland* as *Flutterland: Like Flatland, Only More So* (2001); and as mentioned in the previous chapter, there are several modern incarnations of Mr Tompkins, including Russell Stannard's *The New World of Mr Tompkins* (1999). Notably, in the reissues of both works the fictional component proved to be as much in need of updating as the factual part. These rewritten texts were published around the same time that the third and most recent scientific fantasy discussed here appeared: *Alice in Quantumland* (1995) by particle physicist Robert Gilmore. As the title suggests, Gilmore uses an already-known fantasy universe, Lewis Carroll's Wonderland from *Alice's Adventures in Wonderland* (1865) and *Through the Looking-Glass* (1871), to explain science.

⁶ Abbott Abbott, *Flatland*. The author takes his double surname from his parents, who were first cousins bearing the same surname. Misunderstanding of this name, as well as stylistic considerations, have led to most criticism referring to him as Abbott, in the singular, a convention I adhere to in the body of the thesis.

One issue the scientific fantasy in particular can address effectively is that of scale. As discussed in the previous chapter, the difficulty of conveying an accurate impression of the scales involved is a major obstacle in popularizations of modern physics: works on quantum physics deal with phenomena so small that it is physically impossible to observe them; works on general relativity cover scales too large for the mind to comprehend. Works on astronomy incorporate both extremes of the size scales, as well as extreme scales of time: the big bang took place 13.7 billion years ago, but the most interesting parts of it took place at timescales of the Planck length. Whereas the works in the previous chapter attempted to overcome this obstacle by using the human body as an anchoring point to which they kept returning, the works under discussion here feature human(oid) characters who are themselves changed in scale so that they can experience the phenomena first-hand. In order to achieve this re-scaling, a fantastical setting is necessary: the reader must be given an incentive to suspend their disbelief.

The scientific fantasy works best in longer texts, with the structure of a novel. While many popularizations attempt to convey immensely complicated topics in a condensed manner, Dionijs Burger explains that the novel form Abbott presented in *Flatland* was a welcome alternative:

The major contrast with popular science writing lies not only in the novel form in which it is cast, but also in the slow pace inherent therein, at which the uninformed reader is introduced to the material. This is a truly immeasurable finding, which is unique in literature.⁷

⁷ Dionijs Burger, *Bolland: een roman van gekromde ruimten en uitdijend heelal* (1957; repr., Utrecht: Veen, 1983), 7. 'De grote tegenstelling met populair-wetenschappelijke lectuur ligt niet alleen in de romanvorm waarin het is gegoten, maar ook in het daaraan verbonden langzame tempo, waarin de niet-ter-zake-kundige lezer in de stof wordt binnengevoerd. Dit is een werkelijk onschatbare vondst, die uniek is in de literatuur.' My translation.

In the previous chapter, we saw that Stephen Hawking's *A Brief History of Time*, contrary to *Flatland*, set the pace too high for its readers.

In this chapter, I will argue that metaphor, analogy and allegory can be employed more effectively in scientific fantasies than in regular popularizations. I will discuss the position of didacticism in fiction, and will attempt to answer the question why an author would choose to frame informative writing in a fantastic story, especially in the context of the abstractions of modern physics.

Metaphor, Analogy, and Allegory in Didactic Literature

The didactic function of literature has been long and hotly debated. Whereas Edgar Allan Poe called didacticism in literature 'a heresy too palpably false to be long tolerated,'⁸ literature with a primarily or even solely didactic function has always been produced. Fictional settings are used to create hypothetical situations through which the particular relevance of a certain lesson can be emphasized. Fictional tropes also have a long history in scientific education, as explanations can be made simpler and more accessible through the use of metaphor, analogy and allegory; this use of fiction in didactic writing can be traced back as far as Plato's *Politeia* and Lucretius's *De Rerum Natura*, and later flourished in medieval literature.

Some critics reject the use of metaphor in scientific writings while considering analogy acceptable. An analogy involves a comparison between two relations that teases out resemblances: A is to B like C is to D. A simile is a more direct comparison: A is like B. Daniela M. Bailer Jones points out that analogy may be used in two ways in

⁸ Edgar Allan Poe, 'The Poetic Principle', *Home Journal*, no. 36 (31 August 1850): 1.

science: ‘as formal relationships between phenomena or, rather, between the theoretical treatment of phenomena.’⁹ Analogy is central to science, and is used as a heuristic tool: by finding resemblances between apparently unrelated phenomena, connections and similarities can be teased out. This relation between analogy and scientific process has been advocated for millennia, and can be found in Aristotle’s writings.¹⁰ The fantastical setting of the works in this chapter facilitates the creation of new analogies, not just between different scientific fields, but also between the science discussed and more familiar aspects of the reader’s frame of reference. One such theoretical treatment can be found in quantum physics, where the analogy between the behaviour of a wave, along with the equation representing it, and the way in which the behaviour of electrons could be mathematically represented, led Schrödinger to invent a wave equation for quantum behaviour.¹¹

A metaphor, on the other hand, ‘constitutes a displacement and an extension of the meaning of words’.¹² The referent and the metaphor are further removed from each other; the referent does not have to be mentioned at all, whereas in analogy, it is kept present. Metaphor is a key element of popular science: in nearly every case where an author has chosen not to include equations, the author has opted for metaphor instead. In the case of quantum physics and general relativity, visualizing the phenomena relies

⁹ Daniela M. Bailer Jones, ‘Models, Metaphors and Analogies’, in *The Blackwell Guide to the Philosophy of Science*, ed. Peter Machamer and Michael Silberstein (Oxford: Blackwell Publishers Ltd, 2008), 108–27, <https://doi.org/10.1002/9780470756614.ch6>, p. 110.

¹⁰ W. H. Leatherdale, *The Role of Analogy, Model, and Metaphor in Science* (Amsterdam: North-Holland, 1974), 30.

¹¹ Schrödinger, ‘Quantisierung als Eigenwertproblem (Quantization as an Eigenvalue Problem)’.

¹² Paul Ricoeur, ‘Introduction’, in *On Metaphor*, ed. Sheldon Sacks (Chicago: University of Chicago Press, 1979), 3–8, p. 3.

heavily on metaphor, if only to overcome the problem of scale: to this purpose, scientific fantasies build a narrative around related metaphors of shrinking, growing, or otherwise changing shape. This power of visualization is the pictorial function of metaphor noted by Paul Ricoeur, its ‘ability to “set before the eyes” the sense that they display.’¹³ All of the works discussed in this chapter are illustrated, a rare approach for works for adults; these illustrations are based on metaphors concerning phenomena readers will never be able to observe with the naked eye.

The scientific fantasy contains a unique form of metaphor. As Michael Whitworth points out, metaphors define ‘the intangible in terms of the tangible.’¹⁴ The metaphors in the scientific fantasy do so literally, creating a ‘fantastical estrangement’ in the reader: through the use of a fantastic setting, the reader looks at the scientific content in a way they will never have done before. *Flatland’s* two-dimensional protagonist asks for physical proof that his visitor is three-dimensional and would therefore be able to touch his insides. The visitor obeys: the narrator feels a sharp pain in his gut. The unimaginable fourth spatial dimension is made physically tangible to the readers: a being from the fourth dimension would have unobstructed access to a human’s insides. In Mr Tompkins’s dreams, he is able to communicate with particles, and asks them to explain their behaviour; they drag him along in their wild movements. Mr Tompkins can feel the effects of length contraction and time dilation, and he can see covalent bonds forming. Although a scale change does not in itself constitute a metaphor, the scale changes involved here function to make the intangible literally tangible to Mr Tompkins.

¹³ Ricoeur, ‘The Metaphorical Process as Cognition, Imagination, and Feeling’, p. 142.

¹⁴ Whitworth, *Einstein’s Wake*, 6.

Not everyone has welcomed the use of metaphor in popularization as a tool to make abstract knowledge more accessible. Cloître and Shinn strongly criticize all use of metaphor in popularization, claiming that knowledge derived from metaphors is “degenerated knowledge”, that is to say, knowledge which is so constituted that the nature and relationships of its component elements totally preclude an unequivocal, or even, a coherent “multivocal” grasp of the phenomena.’ Such degenerated knowledge, they assert, ‘is so distended and distorted, with respect to the initial phenomenological referent, that no mental operations based on the metaphors alone enable a reader to retrieve the phenomenon in question.’¹⁵ By making this claim, the authors fail to acknowledge the role of metaphor in scientific writing. Even in specialist science texts, authors resort to metaphorical language to describe their observations. Human beings can only share knowledge through rhetoric-infused language, Gillian Beer reminds us:

Though the events of the natural world are language-free, language controls our apprehension of knowledge, and is itself determined by current historical conditions and by the order implicit in syntax, grammar, and other rhetorical properties such as metaphor, as well as by the selective intensity of individual experience. Even despite the mathematisation of science, discourse can never be expunged from scientific *enquiry*. And nor, perhaps, can narrative.¹⁶

Beer points out that the choice for culturally or rhetorically influenced terminology can be a deliberate and productive move by the scientists employing it. One example is the term ‘black holes.’ Black holes are whimsically named, Beer explains, so that the name can ‘deliberately evade severe equivalence in order to allow space for correction and enhancement without the need constantly to replace and to move on from terms.’¹⁷ The

¹⁵ Cloître and Shinn, ‘Expository Practice’, 48.

¹⁶ Beer, *Darwin’s Plots*, 46.

¹⁷ Beer, *Open Fields*, 157.

term continues to be employed even though black holes are not black,¹⁸ nor are they holes. Their name was never intended to be a description of their physical properties. The name came into being through a problematic comparison that was drawn at a 1967 conference when these regions of spacetime, which have a gravitational field so strong that they swallow everything in their vicinity, including light, were likened by a speaker to the Black Hole of Calcutta.¹⁹ The term 'big bang' serves a similar purpose; as described in the previous chapter, it originated from Fred Hoyle's disagreement with this theory of the origin of the universe. The term remains in use even though there cannot have been an actual 'bang' in a vacuum universe; the name problematizes popular understandings, as one cannot infer the absence of sound in a vacuum from the name of the theory. The cultural rather than scientific origin of the term absolves it from the demand for scientific accuracy, which would cause scientific concepts to constantly have to be renamed as knowledge about the concept increases.

Metaphor is even more important in popularizations than in specialist science writing, because the reader's frame of reference is further removed from the topic under discussion. Gamow's work is an excellent example of a popular science text that combines chapters that are entirely based on metaphor with chapters containing scientific expository writing that employ far fewer metaphors and analogies, and instead rely on equations: Cloître and Shinn rightly claim that no popular science text can function 'based on the metaphors alone'.²⁰ However, they offer a too exclusionary view of

¹⁸ Ian Stewart, *Flatterland: Like Flatland, Only More So* (London: Pan, 2003), 223.

¹⁹ Marcia Bartusiak, *Black Hole: How an Idea Abandoned by Newtonians, Hated by Einstein, and Gambled on by Hawking Became Loved* (New Haven: Yale University Press, 2015), 137.

²⁰ Cloître and Shinn, 'Expository Practice', p. 48.

metaphor. Certainly in the case of quantum physics, analogy is essential, and metaphor is almost equally important.

Cloître and Shinn argue that analogy does not lead to ‘degenerated knowledge,’ because in analogy ‘similarities and limitations are always stipulated,’²¹ but in book-length expositions, the distinction between the two can become blurred. An extended metaphor is much easier to maintain than an extended analogy: with an extended analogy, the comparison needs to be redrawn again and again, whereas the connection between both sides of the metaphor only needs to be stated once, if at all. Thus, in *Mr Tompkins in Wonderland* Mr Tompkins meets the animals in the quantum jungle, but the fact that these animals represent real subatomic particles is not foregrounded until the next chapter. Mr Tompkins does not find himself in a dream world where tigers and gazelles exhibit behaviour that is *like* that of quantum phenomena; instead, they *are* exhibiting quantum behaviour.

The choice of a specific metaphor carries with it implications for the aspects that the communicator intends to foreground. Metaphors can be used to heighten importance, or to diminish it.²² Thus Gilmore emphasizes the strangeness of the quantum world without having to call explicit attention to it, by referring to the familiar bizarre world of *Alice in Wonderland*. Metaphor is also used to achieve conciseness, an important objective in popularization. As Wayne C. Booth points out, trying to unpack the entire content of a single metaphor might take several paragraphs.²³ Through meta-

²¹ Cloître and Shinn, 48.

²² Wayne C. Booth, ‘Metaphor as Rhetoric: The Problem of Evaluation’, in *On Metaphor*, ed. Sheldon Sacks (Chicago: University of Chicago Press, 1979), 55.

²³ Booth, 55.

phor, the author is able to compress the contents of the work without losing its explanatory power, which makes it easier to maintain the attention of the reader. In scientific fantasy, moreover, one metaphor can set up the framework for the entire popularization, which means that the author does not have to come up with new metaphors and explanations for every newly introduced phenomenon.

Despite the protests of some critics, then, both metaphor and analogy are effective communication tools in didactic writing. The scientifically fantastic story brings all explanatory tropes together under a single theme, which heightens the reader's ability to recognize connections and understand the explanation. Such a story is able to visualize phenomena and make them tangible to the protagonist in ways that a realistic narrative would not be able to. In order to see why I chose to hold on to the term 'scientifically fantastic' rather than considering the works discussed here to be part of the science fiction or fantasy genre, it is necessary to look at these genre definitions more closely.

Genre Definitions

George Gamow's Mr Tompkins books were published during what is now known as the United States' 'Golden Age' of science fiction; Gamow's coinage of the term 'scientifically fantastic story', in the introduction to *Mr Tompkins in Paperback* (1965), seems to have been a response to people who had started pigeonholing the first works as science fiction. Gopnik and Gopnik, for instance, label the *Mr Tompkins* books as 'At once, SF

and the stuff of which SF is made.²⁴ Incidentally, Gamow's work is to this day sometimes called science fiction: the web page of the University of Colorado dedicated to Gamow's work lists *Mr Tompkins* as science fiction, while at the same time emphasizing its status as prizewinning popular scientific writing.²⁵ However, as discussed in the Introduction, in the academic study of science fiction there is no single generally accepted definition of the genre, and many science fiction experts deliberately refuse to present a definition.

The *OED*'s synoptic definition of science fiction highlights the problems indicated by those who refuse to define the genre. The definition reads as follows:

Fiction in which the setting and story feature hypothetical scientific or technological advances, the existence of alien life, space or time travel, etc., *esp.* such fiction set in the future, or an imagined alternative universe. Originally with reference to literature; now also to film, television, etc.

Occas. used more narrowly to designate fiction based on possible or probable advances in technology; freq. in contrast to science fantasy.²⁶

This definition differs markedly from the earlier *OED* definition that both Baker and Roberts cite, which called science fiction 'fanciful fiction,' and emphasized the 'imaginative' aspect of the fiction and the possibility that a science fiction work can be based on 'spectacular environmental changes'.²⁷ The most interesting aspect of the latest *OED* definition is the contrast that is made between science fiction and science fantasy, the latter having its own lemma:

²⁴ I. Gopnik and A. Gopnik, 'A Brief and Biased Guide to the Philosophy of Science for Students of Science Fiction', *Science Fiction Studies* 7, no. 2 (1 July 1980): 203.

²⁵ 'The Distinguished Life and Career of George Gamow', *Department of Physics, University of Colorado Boulder* (blog), 2013, <http://phys.colorado.edu/public-outreach/distinguished-life-and-career-george-gamow>.

²⁶ 'science fiction, n. and adj.', *OED Online* (Oxford University Press), accessed 28 August 2017, <http://www.oed.com/view/Entry/172674>.

²⁷ Adam Roberts, *Science Fiction*, 2000. 2nd ed (London: Routledge, 2006), 3–4; Baker, *Science Fiction: Reader's Guides to Essential Criticism*, 7.

- a. A genre of fiction that combines elements of science fiction and fantasy; (also) a work in this genre.
- b. Science fiction which is characterized by the depiction of technologies generally regarded as scientifically impossible; (also) a work of this type.²⁸

The *OED* defines 'fantasy' in its literary sense as 'a genre of literary compositions' without further defining the criteria for inclusion in this genre.²⁹ Definition a) resembles the definition given by the *Encyclopedia of Science Fiction*: 'Science Fantasy is normally considered a bastard genre blending elements of sf and fantasy; it is usually colourful and often bizarre, sometimes with elements of Horror although never centrally in the horror genre.'³⁰ These definitions of the 'scientific fantasy' are markedly different from that of the 'scientifically fantastic story' used in this chapter. Definition b. does not seem to hold up under close scrutiny. Margaret Atwood used this definition to emphasize that her dystopian novel *Oryx and Crake* should *not* be regarded as science fiction: she argues it is speculative fiction, because the science in the novel is neither hypothetical nor scientifically impossible.³¹ Such a claim, regarding a book in which chickens without brains, pigs with human brains, and a humanoid species with blue genitals are featured, was met with scorn by some science fiction authors and critics.³² As indicated in the Introduction, both the concept of the novum and that of extrapolation are based on a divergence from the scientific status quo.

²⁸ 'science fantasy, n.', *OED Online* (Oxford University Press), accessed 28 August 2017, <http://www.oed.com/view/Entry/402743>.

²⁹ 'fantasy | phantasy, n.', *OED Online* (Oxford University Press), accessed 5 May 2017, <http://www.oed.com/view/Entry/68119>.

³⁰ Peter Nicholls, 'Science Fantasy', ed. John Clute et al., *The Encyclopedia of Science Fiction* (London: Gollancz, 2 April 2015), http://www.sf-encyclopedia.com/entry/science_fantasy.

³¹ Margaret Atwood, 'The Handmaid's Tale and *Oryx and Crake* "In Context"', *PMLA* 119, no. 3 (May 2004): 513–517.

³² Ursula K. Le Guin, 'The Year of the Flood by Margaret Atwood', *The Guardian*, 29 August 2009, sec. Books, <https://www.theguardian.com/books/2009/aug/29/margaret-atwood-year-of-flood>.

The emphasis on the 'hypothetical' in the OED definition marks the point of distinction between science fiction and the scientifically fantastic. Gamow's resistance to having his Mr Tompkins books labelled as science fiction likely has to do with this particular aspect of the genre, as it directly affects the way in which the scientific content is perceived. Scientifically fantastic works are not meant to extrapolate from the scientific status quo: they are written in order to introduce the reader to current developments in science.

As we have seen, a simple dictionary definition is unable to clearly separate the two genres of fantasy and science fiction; they evolved from a shared origin. Adam Roberts attempts to distinguish between the two by claiming that 'it makes sense to separate out "*science fiction*" from "*fantasy*" on the grounds that the latter is magical; it always includes an excess that cannot be reconciled with, or explained, in terms of the world as we know it really to be.'³³ Although magic and science have in the past met, for instance in alchemy, the two indeed seem to be mutually exclusive in nearly all modern fiction. In works that contain magic but no science, magic often takes the position science holds in the real world: it is institutionalized, taught, constrained by severe linguistic rules. In discourses where the two meet, one is normally considered inferior to the other. Whereas there are fictional works in which magic is superior to science, such as *Harry Potter*, in nonfictional discourse magic is nearly always inferior: as quoted at the start of this chapter, Arthur C. Clarke posits belief in magic as a display of lack of scientific understanding, a position which Tom Shippey traces all the way back

³³ Adam Roberts, 'The Copernican Revolution', in *The Routledge Companion to Science Fiction*, ed. Mark Bould et al. (London: Routledge, 2009), 3-12, p. 3-4.

to Roger Bacon in the thirteenth century.³⁴ This inferiority of magic as opposed to science is often gendered, as Gillian Beer points out in a discussion of anthropological writing: 'Magic is both female and illegitimate, disturbing causality.'³⁵ Science is depicted as superior to magic in its rational masculinity.

However, Roberts's definition is rather too narrow: science fiction, too, can contain an excess, particularly when the author makes extrapolations based on scientific theories that currently have multiple interpretations, or when the author assumes a certain discovery will be made in the future. The distinction I will uphold in this thesis is that, in science fiction, the events that occur could not have taken place without new developments in science and technology, whereas in fantasy these events are presented as having a stable magical origin, which one would not be able to explain rationally outside the text. The events in fantasy novels will never be possible outside the text, whereas with science fiction the hope (or fear) is that they may one day be possible.

According to this definition, the books discussed in this chapter can be considered to belong to the fantasy genre, more so than to science fiction. The fantastical element is used in obvious contrast to the science, and is used to make scientific knowledge more visible and understandable to the reader. Narratives in the fantasy genre present an enclosed, fictional world, which is driven by its own internal logic. The scientifically fantastic narrative, on the other hand, needs to take into account that

³⁴ Shippey, 'The Golden Bough and the Incorporations of Magic in Science Fiction', 162.

³⁵ Beer, *Open Fields*, 76.

its metaphors refer to ‘real things, existing beyond the closed world of one story.’³⁶ The reader will have to be able to distinguish this content from the fantastic elements.

The definition of these stories as popularizations is determined by authorial intention. The first purpose of scientifically fantastic works is to be didactic, although they use a fantastical setting: the reader can, and should, learn about physics from these works. This didactic rather than speculative nature separates the genre from both science fiction and fantasy. The fantastical setting is intended to make the work more appealing, and to make it easier for the reader to grasp the scientific concepts. Although the reader can certainly learn a fair amount of science from many ‘hard’ science fiction works, didacticism, certainly the teaching of scientific subjects, is not the principal objective of the author in either science fiction or fantasy.

Joanna Russ, in ‘Towards an Aesthetic of Science Fiction,’ did claim that science fiction is didactic: ‘Science is to science fiction (by analogy) what medieval Christianity was to deliberately didactic medieval fiction.’³⁷ However, even when science fiction is written with a didactic intent – as for instance science fiction editor Hugo Gernsback, discussed in the Introduction, hoped the writing in his magazines would be – the knowledge transfer Russ describes is still markedly different from that in the scientifically fantastic. She writes that science fiction teaches its readers about knowing, about possessing knowledge:

Science fiction is also the only modern literary form (with the possible exception of the detective puzzle) which embodies in its basic assumptions the conviction that finding out, or knowing about something—however impractical the knowledge—is itself a crucial good.³⁸

³⁶ Jon Ogborn et al., *Explaining Science in the Classroom* (Buckingham: Open University Press, 1996), 10.

³⁷ Joanna Russ, ‘Towards an Aesthetic of Science Fiction’, *Science Fiction Studies* 2, no. 2 (1 July 1975): 113.

³⁸ Russ, 117.

Whereas scientifically fantastic stories, as forms of popularization, are intended to convey specific forms of knowledge, science fiction is intended to convey a view on knowledge as a whole. Notably, Russ's 1975 article presents science fiction as a genre consisting mostly of hypermasculine, American space opera; earlier that year, however, she published the science fiction novel *The Female Man*,³⁹ one of the first works in a wave of works by women that was much more pessimistic about science and the possession of knowledge.

Brian Attebery uses the label 'Natural Fantastic' for works such as *Mr Tompkins in Wonderland*, defining it as 'the depiction of any natural process or product of technology in such a way as to strike us as extraordinary or astonishing.' He defines it as a subgenre of science fiction since it 'falls well within Suvin's definition of SF as the literature of cognitive estrangement'.⁴⁰ I have chosen not to take on Attebery's label, since the term 'natural fantastic' does not carry the connotations I wish to emphasize for the case studies in this chapter: their emphasis on real-world science, their didactic intention, and the absence of questions regarding plausibility, which Latham defines as a key element of science fiction.⁴¹

In a discussion of Dionijs Burger's *Bolland*, J.A. Dautzenberg describes works such as *Bolland* and Abbott's *Flatland* as 'mathematical fantasy':

The vast majority of the mathematical fantasy stories is written to clarify these cases and to show what the ingenuity of the author can accomplish. From a literary point of view they are therefore much more limited than stories in which

³⁹ Joanna Russ, *The Female Man* (New York: Bantam Books, 1975).

⁴⁰ Brian Attebery, 'The Fantastic', in *The Oxford Handbook of Science Fiction*, ed. Rob Latham (Oxford: Oxford University Press, 2014), 131.

⁴¹ Latham, 'Introduction', p. 29.

the mathematical problems are merely the motivation for something else, just like the logical jokes of Carroll are not an end but a means.⁴²

Combining Dautzenberg's term as applied to all sciences with Gamow's term 'scientifically fantastic story' has given me the term I will use throughout the thesis.

Will Tattersdill explains that what he calls 'the material entanglement of genres of literature and science' has a history in nineteenth-century periodical culture. As he points out in a reading of the eugenicist and science writer Francis Galton's 'Intelligible Signals between Neighbouring Stars', Galton

confounds rigorous categorisation, showing not only exchange between the supposed opposites 'science' and 'fiction' but also that each provides essential components without which the article would be incomplete; fiction and the periodical format are not merely window-dressings for a scientific idea, but reinforce the argument and subtly alter it.⁴³

In his article, Galton is making a serious proposal for communication between the Earth and Mars; he embeds the complex, mathematical explanation of his method in a fantasy in which the Martians having sent a message to Earth.⁴⁴ Science and the fantastical are interwoven in two ways: firstly, the periodical as a whole often brought together a miscellany of both fictional and nonfictional writings, leading to a work 'which presents multiple different genres with the same level of locutionary agency, with no clear mech-

⁴² J.A. Dautzenberg, 'Nawoord (Afterword)', in *Bolland: een roman van gekromde ruimten en uitdijend heelal*, by Dionijs Burger (Utrecht: Veen, 1983), 156–63, p. 162. 'Verreweg de meeste verhalen uit de mathematical fantasy zijn geschreven om deze zaken te verduidelijken en om te laten zien wat het vernuft van de schrijver vermag. Literair gezien zijn ze daarom veel beperkter dan verhalen waarin de wiskundige problematiek slechts aanleiding is voor iets anders, zoals de logische grapjes van Carroll geen doel zijn maar een middel.' My translation. Note that Dautzenberg uses the English term 'mathematical fantasy' in his Dutch essay.

⁴³ Will Tattersdill, *Science, Fiction, and the Fin-de-Siècle Periodical Press* (Cambridge: Cambridge University Press, 2016), 31, <http://ebooks.cambridge.org/ref/id/CBO9781316534724>.

⁴⁴ Tattersdill, 35, 37.

anism for demarcating them from one another and no labelling system restricting individual articles to a rigid set of generic criteria.⁴⁵ Secondly, authors such as Galton brought together these two modes within single articles that intend to popularize by speaking to the imagination.

In the twentieth century, however, the scientifically fantastic became an uncommon form in science popularization. One reason may be that a fantastic mode may undermine the truth claim of a work that is aiming to teach the reader objective scientific theories. In the twentieth and twenty-first century, a fantastical allegory no longer seems to be considered an appropriate form for educating adults. The works analysed here are among the very few that make use of fantasy in communicating science; another well-known case is the *Science of Discworld* series by Terry Pratchett, Ian Stewart and Jack Cohen, which covers nearly all scientific fields.⁴⁶ Fantasy is still widely used in works for children, in which there is a long tradition of using allegory to communicate science. As the next chapter will discuss in more detail, all popularizations of quantum physics aimed at children frame the explanation in a scientifically fantastic story. The works discussed here, however, are unusual in their combination of form and intended audience.

⁴⁵ Will Tattersdill, 'Looking at the Issues: Science and Fiction as Genres in the *Fin de Siècle* Magazine', *Textual Practice* 31, no. 2 (23 February 2017): 417–31, <https://doi.org/10.1080/0950236X.2016.1249706>, p. 419.

⁴⁶ Pratchett, Stewart, and Cohen, *The Science of Discworld*; Pratchett, Stewart, and Cohen, *The Science of Discworld II: The Globe*; Pratchett, Stewart, and Cohen, *The Science of Discworld III: Darwin's Watch*; Pratchett, Stewart, and Cohen, *The Science of Discworld IV: Judgement Day*.

Flatland, Bolland and Flatterland

Edwin Abbott's *Flatland, or, a Romance of Many Dimensions* (1884) is a fantastical story that explains the concepts of multidimensionality; at the same time, it is a fierce criticism of the rigid social structures of Victorian England. A. Square, the main character, is a square who spends the first half of the book explaining the hierarchical social structure of the two-dimensional country Flatland, in which the number of angles one has determines one's place in society. Women, being straight lines, reside at the very bottom of the societal strata. One day, a sphere visits Mr Square and lifts him into a three-dimensional world. Upon returning, his inability to explain the concept of the third dimension to his narrow-minded fellow Flatlanders causes him to become a social outcast.

The scientific content of the book is comprehensible to children. Abbott was a schoolmaster, and his geometric analogies are directly based on textbooks that teach Euclidean geometry. The narrator at times facilitates understanding by a younger audience through phrases such as, 'Yet for the sake of the young and inexperienced [...] it may be needful to point out [...]'.⁴⁷ However, the strongly present social criticism seems to be aimed at an adult audience. Abbott's allegory is intended to make the reader aspire to understand 'the Secrets of Four Five or even Six Dimensions',⁴⁸ and, at the same time, to realise how ridiculous the social hierarchies of Victorian England were. His work is designed to be read like a novel, the reader being immersed in the fantastical

⁴⁷ Edwin Abbott Abbott and Ian Stewart, *The Annotated Flatland: A Romance of Many Dimensions* (Cambridge, MA: Perseus Press, 2002), 68.

⁴⁸ Abbott Abbott and Stewart, 7.

universe of Flatland throughout. The explainer, the Sphere, is part of this fantasy universe. Most other scientific fantasies are not fully immersive: Gamow and Gilmore included explanatory chapters and footnotes which explain the fantasy in terms of real-world occurrences. Ian Stewart's annotations in *The Annotated Flatland* turn the work into a similar kind of alternation between fantasy and realism: Stewart adds a chapter in which he explains the mathematical origins of the fourth dimension in a nonfictional form.⁴⁹

Critics disagree on defining the genre of *Flatland* due to this mix of satire and science. Ian Stewart calls the book a 'mathematical fantasy' in the introduction to *The Annotated Flatland*, explaining that it cannot be considered 'hard science fiction.'⁵⁰ He supports this premise by pointing out that Abbott gives no explanations based on science and/or technology for the strange experiences the narrator undergoes. Its status as a fantasy implies that it 'makes no attempt to be logically consistent in every respect.'⁵¹ Elizabeth L. Throesch, on the other hand, argues that, since the analogy is used 'as the foundation for a fiction that is ultimately designed to deflect the reader's attention back outward' to their own world, '*Flatland* relies on "science" as a foundation for its fiction, performing a function similar to that of much traditional science fiction.'⁵² Whereas the scientific element was originally subordinate to the satirical message about society, the book's function as a science popularization proved to be most influential in the subsequent centuries.

⁴⁹ Abbott Abbott and Stewart, 203–29.

⁵⁰ Abbott Abbott and Stewart, xiii.

⁵¹ Abbott Abbott and Stewart, 26.

⁵² Elizabeth Throesch, *Before Einstein: The Fourth Dimension in Fin-de-Siècle Literature and Culture* (London: Anthem Press, 2016), 26.

Flatland has inspired authors since its first publication, which was followed by a second edition within a month. It is probably the most famous work to explore the fourth spatial dimension in fiction, but Throesch points out that Gustav Theodor Fechner's essay 'Der Raum hat vier Dimensionen' (1846) was the first.⁵³ Throesch coins the term 'dimensional analogies' for this genre,⁵⁴ which subsequently included Hal Clement's *Mission of Gravity* (serialized in 1953) in which a planet is discovered that has such a high gravity that its life is confined to two dimensions, and Rudy Rucker's *Spaceland* (2002) in which a man called Joe Cube is visited by a four-dimensional being.⁵⁵ *Flatland* itself is referred to in Robert Heinlein's *Stranger in a Strange Land* (1961), when Dr. Harshaw tries to explain to his aide, Duke, where the objects have gone that the Man from Mars can make disappear:

'Duke, the cameras are okay. What is ninety degrees from everything else?'
 'I'm no good at riddles.'
 'It's not a riddle. I could refer you to Mr. A. Square from Flatland, but I'll answer it. What is perpendicular to everything else? Answer: two bodies, one pistol, and an empty case.'⁵⁶

The reader who is familiar with Abbott's work is at an advantage here: such a reader can infer that the objects have been moved into a fourth spatial dimension. This explanation is not given explicitly, as the above quotation shows. This reference suggests that eighty years after its publication, *Flatland* was still widely read among the audience Heinlein intended for his writing.

⁵³ Throesch, 24.

⁵⁴ Throesch, 24.

⁵⁵ Hal Clement, *Mission of Gravity* (1954; repr., London: Hale, 1955); Rudy Rucker, *Spaceland* (2002; repr., New York: Tor, 2003).

⁵⁶ Robert A. Heinlein, *Stranger in a Strange Land*, 1961. Ebook (New York: Ace Books, 1987).

The 2014 film *Interstellar* relies on a similar concept in which the main character, Cooper, enters a five-dimensional spacetime – four dimensions of space and one of time – which is visualized in such a way that he is able to comprehend its structure. This visualization is a direct intertextual reference to Abbott. Kip Thorne, professor of theoretical physics and scientific advisor/executive producer of *Interstellar*, dedicates a chapter of *The Science of Interstellar* to Abbott's book: 'Though its satire on Victorian culture seems quaint today and its attitude toward women outrageous, the novella's venue is highly relevant to *Interstellar*. I recommend it to you.'⁵⁷ He then uses an analogy based on *Flatland* to explain what a five-dimensional being would look like if it passed through our four-dimensional world.

Thorne here visualizes the analogy Abbott created to make it possible for a reader to begin to comprehend the possible existence of spatial dimensions beyond the third. Abbott makes it clear to the reader that they should see A. Square's struggle to understand, and the manner in which he resolves it, as a partial solution to the problem of understanding more than three spatial dimensions. The explanation of Square's situation fits into his readers' understanding of the universe, and they should extrapolate this explanation to the many more spatial dimensions that seem to exist. Although such dimensions were long known to be a mathematical possibility,⁵⁸ not until the twentieth century did it become clear how many applications for multi-dimensional thinking there could be. String theory and the many-worlds interpretation of quantum physics, for instance, in some forms rely on many dimensions not observable to us. The most

⁵⁷ Kip S. Thorne and Christopher Nolan, *The Science of Interstellar* (New York: W.W. Norton & Company, 2014), 189. Thorne seems to have misunderstood the satire of sexism just like many other readers have done, and misquotes the publication date of *Flatland* as 1844 rather than 1884.

⁵⁸ Abbott Abbott and Stewart, *The Annotated Flatland*, 13.

common interpretations of string theory currently assume ten spatial dimensions; the many-worlds interpretation depends on two-dimensional time;⁵⁹ whilst contemporary mathematics can work with an infinite number of dimensions. Dionijs Burger and Ian Stewart showed that it was necessary to re-interpret Abbott's concept of multidimensionality in order to be able to explain concepts from modern physics in a popular work.

The best-known sequel to *Flatland* is Dionijs Burger's *Bolland: Een roman van gekromde ruimten en uitdijend heelal* (1957, translated into English in 1965 as *Sphereland: A Fantasy About Curved Spaces & an Expanding Universe*).⁶⁰ Burger, who had a doctorate in mathematics and physics, wrote a physics- rather than mathematics-oriented sequel to *Flatland* which is relatively faithful to Abbott's original narrative. The first chapter of his work is a summary of *Flatland*, so that a modern reader who has not read the work can follow Burger's narrative. As he explains in the introduction, the 1884 Dutch translation of Abbott's work has not been reprinted in the twentieth century.⁶¹ The *Bolland* story is told by a hexagon, the grandson of A. Square who in *Flatland* seemed most susceptible to the concept of three dimensions. He starts off by explaining how much society has changed in two generations: after his death, his grandfather became revered, as the truth of his sayings became known. The position of women has improved, although the narrator is of the opinion that women are simply much better

⁵⁹ In the many-worlds interpretation, parallel worlds lie alongside each other along one temporal dimension; a second temporal dimension would allow for movement from one parallel world to another.

⁶⁰ Dionijs Burger, *Sphereland: A Fantasy about Curved Spaces and an Expanding Universe*, trans. Cornelia J. Rheinboldt (New York: Crowell, 1965). The English translation lacks the pun on 'Holland', which means the opposite of 'Bolland': the two words translate as 'concave land' and 'convex land'.

⁶¹ Burger, *Bolland*, 7. The translation in fact has never been reprinted.

sued to household work – this explanation is not obviously satirical.⁶² The story continues where *Flatland* ended: the Sphere continues to visit the hexagon each New Year's Eve. Burger adds both to the fiction of *Flatland* and to its mathematical content. The hexagon and his scientist friend Puncto find a way to prove that their two-dimensional world is curved, so that in three dimensions it forms a sphere: Flatland is in fact a Sphereland.⁶³ The scientific establishment ridicules the two scientists for this finding: scientific conflict is still rife in Sphereland.

As the term 'expanding universe' in the title suggests, the final chapters address the origin of the Sphereland universe. The narrator and Puncto discover that Sphereland is located in an expanding universe; when they present these findings to the scientific committee, they are met once again with ridicule. The Sphere, however, on his next New Year's Eve visit, confirms the findings of the two men. Writing even before Gamow, in 1957, Burger shows that the steady-state theory may have gained less of a foothold in the Netherlands in the mid-twentieth century: the Sphere adds that his own three-dimensional universe is expanding, too.⁶⁴

For Burger, then, the form and content of *Flatland* are both updated, but the original work is kept in mind for both. The combination of form and content is maintained. Mathematics popularizer Ian Stewart, who also co-authored the aforementioned *The Science of Discworld* series, wrote a more recent sequel to *Flatland*. In this work, he too briefly updates Abbott's narrative, but then moves on to the introduction of new content, which makes up by far the largest part of the work.

⁶² Burger, 31.

⁶³ Burger, 127.

⁶⁴ Burger, 149, 151.

Stewart's *Flatterland: Like Flatland, Only More So* (2001) presumes that the reader is familiar with the main characteristics of the original work: the two-dimensional society, the square protagonist, and the linear women. The contents of this book, however, diverge dramatically from Abbott's work, as Stewart draws on twenty-first-century mathematics. This story is set a century after Abbott's original work. The protagonist is a young Line, Victoria ('Vikki'), whose use of language appeals to a teenage audience of Stewart's time. The rigid social stratification has partly disappeared from Flatland, and is sometimes remarked upon as an embarrassment of the past which society has not yet entirely been able to erase. In the opening chapter Vikki finds the manuscript of *Flatland: A. (Albert) Square* is her great-great-grandfather. She finds a puzzle hidden in the manuscript, and upon deciphering it, manages to summon a Space Hopper, a creature which is able to transport her through a multidimensional multiverse called the Mathiverse. Through a device called the VUE (Virtual Unreality Engine), Vikki is able to observe phenomena and hypothetical situations in mathematics and physics that would normally not be observable to the human eye. As in Abbott's original work, both the scientific and fantastic content appear within the same chapter, interspersed with diary fragments in which Vikki reflects on the new phenomena she encounters, summarizes them, and occasionally asks questions to introduce the next topic.

The Space Hopper is introduced to show Vikki, and the reader, that our universe has more than three dimensions, depending on one's definition of a dimension: Stewart's book goes beyond analogous suggestion and lets the Space Hopper explain precisely how these dimensions would work, if 'dimension' is defined as 'dependence on

variables.⁶⁵ Vikki points out in her diary that the mathematical perspective on multidimensionality has changed since her grandfather narrated his experiences: 'by the time Yours Truly got to visit Planiturth the fickle creatures had changed their minds. No longer did they imagine their world to be an ideal 3D Euclidean Space. Not a bit of it. It had become a 4D Spacetime.'⁶⁶ This new definition invalidates much of the effort Abbott made in his original work to explain the concept of multiple dimensions through analogy. Stewart only derives the fictional elements from Abbott's work, and hardly any of the scientific content of *Flatland*, since this science is now outdated. Stewart moves away from Abbott's work in form as well as content, but holds on to Abbott's scientific fantasy as a peg for explaining twenty-first-century views on multidimensionality in a familiar context.

It is difficult to determine the audience for Stewart's book. Stewart inverts Abbott's expectations of his audience: whereas Abbott's mathematics were aimed at schoolchildren and the contents of his book at adults, Stewart writes in a language aimed at teenagers but introduces concepts that readers would normally only learn about beyond secondary school education. Since the 'sequel' is aimed at a younger audience than the original, it is unlikely that a modern reader would read both works, let alone in the intended order. However, the first chapters in particular are a knowing tribute to Abbott's work, meaningful only to a reader who is already familiar with *Flatland*: it is much more reliant on the original work than other works discussed in this chapter which are derived from earlier texts, such as *The NEW World of Mr Tompkins*

⁶⁵ Stewart, *Flatland*, 46–47.

⁶⁶ Stewart, 188–89. This concept had in fact already been introduced by Lagrange in the eighteenth century.

or *Alice in Quantumland*. The fact that Vikki is two-dimensional does not seem to have been necessary for large parts of the adventures she and the Space Hopper encounter. Her shape in fact obstructs the narrative when Stewart discusses Vikki's left and right shoes in order to explain one-sided surfaces, after which he has to explain to the reader why a line-shaped creature like Vikki can wear two shoes at all.⁶⁷ Stewart adopted the already-known fantastical world of *Flatland* without the purposes for which it was written: its social criticism has disappeared, and its didactic purpose of explaining the fourth spatial dimension to readers only occupies a paragraph in *Flatterland*, as the reader is made to think about dimensionality in different ways. *Flatland* has become an analogical world onto which all kinds of scientific concepts can be projected.

The extent to which the world of *Flatland* was revised to fit Stewart's work suggests that the trope of a two-dimensional world overshadowed both the scientific and the social justice contents of the work. *Flatterland* goes beyond simply updating the science to match twenty-first-century knowledge, as Burger did. While relying on Abbott's original fantasy world, Stewart assumes that the reader is familiar with the mathematics discussed in *Flatland* and instead writes about entirely new, often much more complicated, scientific topics, including quantum physics. The topic of scale enters the narrative here, though it was not part of Abbott's original work: the Space Hopper shrinks Vikki and itself to a size small enough to observe quantum effects. Whereas the mathematical contents of Abbott's work did not exceed the level of primary-school Euclidean geometry, Stewart adds concepts and puzzles that require further schooling.

⁶⁷ Stewart, 110–11.

Stewart shows that the world of *Flatland* and the concepts it explains can be separated from each other while keeping the allegorical world intact. Abbott's fantasy proves to be such an effective explanatory tool that it can be re-used to aid new explanations. Stewart uses a known setting to achieve a much more in-depth engagement with mathematics than Abbott originally offered. This use of an already-known fantasy setting to explain new scientific concepts can also be seen in the *Mr Tompkins* series and its derivatives. Although more of the original fantasy can be preserved, because less time has passed between this book and its derivatives than in the *Flatland* case, again the original fantasy is found to be worthy of preserving regardless of its scientific or cultural contents.

Mr Tompkins and its Remakes

George Gamow's *Mr Tompkins* series was first introduced in the previous chapter. Whereas the discussion there focused on the relationship between his popularizations and Fred Hoyle's, this chapter will cover the discursive form Gamow chose for this series. Elizabeth Leane calls the works a 'quantum fable' in which 'an extended anthropomorphic conceit is employed in order to explain the paradoxical and nonsensical world of the new physics.'⁶⁸ The fantastic is employed in order to make anthropomorphization possible. Gamow resizes physical phenomena in order to enable Mr Tompkins to experience them at the human scale in his dreams. Physics is made to fit human sensory experience, and particles and forces are given humanoid identities.

⁶⁸ Leane, 'Contemporary Popular Physics', 45, 189.

In *The NEW World of Mr Tompkins*, Russell Stannard's 1999 remake of *Mr Tompkins in paperback* aimed at 'anyone above mid-teens', Stannard paid as much attention to rewriting the fiction as to rewriting the science, just as had been done with *Flatland*.⁶⁹ At first sight, the science seems to have been much more in need of updating than the fictional component, especially as Gamow did not intend the fictional component to carry any higher message about society, as Abbott's story had done. The science had become partially outdated, as Stannard pointed out: 'so much having happened in the 30 years since the last revision, especially in the fields of cosmology and high energy nuclear physics.'⁷⁰ With this claim, Stannard directly contradicts Roger Penrose's claim made in the introduction to the 1993 edition of *Mr Tompkins in Paperback*, quoted in the previous chapter: Penrose wrote that the fundamental scientific ideas presented in the book had not changed, apart from those concerning particle physics. Since particle physics in fact makes up most of the content of *Mr Tompkins explores the atom*, an update might have been in order after all. Stannard explains that the social dynamics in the book were in equal need of an update because of the assumptions they made about society. He singles out the case of Mr Tompkins's wife Maud as being particularly outdated: the 'girlie' is told to run off when the men are about to start a conversation on physics. Also, he asks, 'ought one to be introducing quantum theory by reference to a tiger shoot, given our modern-day concern for endangered species?'⁷¹ The previous chapter addressed Stannard's decision to keep the Cosmic Opera in the book; Stannard rewrote the opera chapter so that its contents were no longer fantastic.

⁶⁹ Russell Stannard, 'Communicating Physics through Story', *Physics Education* 36, no. 1 (2001): 30–34, p. 31.

⁷⁰ Gamow and Stannard, *The NEW World of Mr. Tompkins*, vii.

⁷¹ Gamow and Stannard, vii.

In Gamow's original work the Cosmic Opera was part of the fantasy, as Mr Tompkins fell asleep during a real opera and dreamt this scientific version. Stannard removes the fantasy element from the opera by turning it into an actual performance put on by students and faculty at the physics department where Maud's father is the professor. The opera becomes a history lesson, rather than a fictional representation of a contemporary scientific conflict.

Like *Flatland*, the Mr Tompkins books became standard models for science communication that were frequently updated, adapted, and used for the communication of science that was developed long after the original books were written. The success of the earlier books created a brand name that stood for a combination of accessible science and amusing fiction. However, both Abbott and Gamow had created products of their time not only in terms of science, but also in terms of social norms: the updating of both aspects shows how science communication illustrates that scientific developments take place in a specific social context and are communicated as such. The authors are willing to cope with narrative conservatism if that means that they can use an overarching narrative for their popularization that has been proven to work: Robert Gilmore's *Alice in Quantumland* borrowed his fiction not from an older popular science work, but from a famous children's book written by a mathematician.

Alice in Quantumland

Particle physicist Robert Gilmore's *Alice in Quantumland: An Allegory of Quantum Physics* (1995) takes the story of Lewis Carroll (Charles Lutwidge Dodgson)'s *Alice's Adventures in Wonderland* (1865) and *Through the Looking-Glass* (1871), nineteenth-century

children's books, to explain twentieth-century physics to adults.⁷² *Alice in Quantumland* was followed by two more books that explained quantum physics by means of retelling classical works of fiction: *Scrooge's Cryptic Carol* (1996), based on Charles Dickens's *A Christmas Carol* (1843), and *The Wizard of Quarks* (2001), based on L. Frank Baum's *The Wonderful Wizard of Oz* (1900).⁷³ Like Abbott's and Gamow's works, *Alice in Quantumland* is an exploration of the ways in which our universe works, seen through the eyes of someone who is not familiar with modern science. Lewis Carroll's narratives are updated to a late twentieth-century setting – Alice falls into the TV, rather than down a rabbit hole or through a mirror – but the illustrations, drawn by the author himself, are based on John Tenniel's original work.

In using the *Alice* books as a stock fantasy setting for science books, Tenniel's illustrations are as important as Carroll's story, regardless of the reader's age. Gilmore's Alice is a slightly older version of Tenniel's Alice, wearing the same clothes and hairstyle; quantum physics concepts are visualized in these drawings alongside these familiar points of reference. Misleading as illustrations of the invisibly small can be, they often offer a possibility for the reader to understand the concept in a way that writing would not have been able to do. As the reader is taught about new concepts, ones they might not even have heard of in school, illustrations will help them understand and remember. A work on quantum physics, however, is difficult to illustrate due to the inherent unobservability of many processes in this field. Gilmore, and Russell

⁷² Lewis Carroll, *Alice's Adventures in Wonderland* (London: Macmillan, 1865); Lewis Carroll, *Through the Looking-Glass, and What Alice Found There* (London: Macmillan, 1871).

⁷³ Gilmore, *Scrooge's Cryptic Carol*; Robert Gilmore, *The Wizard of Quarks: A Fantasy of Particle Physics* (New York: Copernicus, 2001).

Stannard, as discussed in the next chapter, have resolved this issue through a combination of anthropomorphization and reference to Alice in Wonderland, whose illustrations are as familiar as its storyline. The next chapter will further address the use of an *Alice* setting by comparing the work to Russell Stannard's *Uncle Albert and the Quantum Quest*, a quantum physics popularization based on *Alice in Wonderland*.

The narrative of *Alice in Quantumland* itself, although focalized through Alice, is aimed at an adult audience both in terms of the vocabulary that is used and in terms of the events in the book. Alice visits a bank, and an estate agent points out a sex joke to Alice ('Real particles do it on the Mass Shell').⁷⁴ The *Alice* books have been widely embraced by scientists for use in adult contexts, supporting Beer's claim that '*Gulliver's Travels* changed from being an adults' to a children's book; the trajectory of Alice has been in the other direction.'⁷⁵ Alice seems to be depicted as a teenager rather than a young girl: although she wears the same clothes and hairstyle as Tenniel's Alice, she is significantly taller. No comparison to adult female characters can be made, because *all* characters she meets are male, except a mermaid. The mermaid, a school student, explains the many-worlds interpretation, which both Alice and the schoolmaster reject on the basis of it being 'very extravagant with universes!' – Gilmore adheres to the Copenhagen interpretation in this book.⁷⁶ The only adult female character in the book is therefore not considered an expert. This absence of women who are knowledgeable about quantum physics does not seem to have been noted by reviewer Maria Popova,

⁷⁴ Gilmore, *Alice in Quantumland*, 31, 94.

⁷⁵ Beer, *Alice in Space*, 2.

⁷⁶ Gilmore, *Alice in Quantumland*, 61. This is a paraphrase of Paul Davies's claim that 'parallel universes are cheap on assumptions but expensive on universes'. As shown in Table 1, a year later Gilmore presented a much more positive view of the many-worlds interpretation in *Scrooge's Cryptic Carol*. Paul Davies and Julian R. Brown, eds., *The Ghost in the Atom: A Discussion of the Mysteries of Quantum Physics* (1986; repr., Cambridge: Cambridge University Press, 2005).

who in 2014 enthusiastically hailed it as a book that ‘flies in the face of gender stereotypes with a female protagonist’.⁷⁷

Another scientific fantasy for adults based on the Alice books appeared in 2010, when *Physics World* published G.G. Davies’s short story ‘Alice through the Double Slits’.⁷⁸ His story rewrote the first chapter of *Alice in Wonderland* to explain Thomas Young’s double-slit experiment.⁷⁹ In 2014, Davies published *Alice through the Double Slits: A lateral approach to probing physics – in Wonderland* with the *Physics World* story as its first chapter.⁸⁰ The 36-page book, which contains no illustrations, is aimed at adults: the back cover describes it as a story ‘for physics-followers’, and it assumes previous knowledge about the double-slit experiment, general relativity and the big bang. The book introduces ‘a young lady probably called Alice’ who, after having grappled with the implications of the double-slit experiment, takes a break and sits outside, where she sees a ‘White Rabbit’ when she starts to feel drowsy.⁸¹ The rabbit, helped by a field full of other rabbits, proceeds to explain the results of the double-slit experiment in a diction that is certainly not aimed at children:

[The detector] moves [the probability] *from uncertainty to certainty*, at the expense of the inferior probability and the probability field as a whole. The interaction of the detector with the probabilities of many rabbits is thus a series of *localising* events incompatible with the uncertainty inherent in the probability fields of the rabbits’ energy.⁸²

⁷⁷ Maria Popova, ‘Alice in Quantumland: A Charming Illustrated Allegory of Quantum Mechanics by a CERN Physicist’, *Brain Pickings* (blog), 30 January 2014, <https://www.brainpickings.org/2014/01/30/alice-in-quantumland-robert-gilmore/>.

⁷⁸ G.G. Davies, ‘Alice through the Double Slits’, *Physics World* 23, no. 2 (February 2010): 52, <https://doi.org/10.1088/2058-7058/23/02/48>.

⁷⁹ Young, *A Course of Lectures on Natural Philosophy and the Mechanical Arts*, 1:464–65.

⁸⁰ G. G. Davies, *Alice through the Double Slits: A Lateral Approach to Probing Physics – in Wonderland* (Birmingham: WWAM Writers Ltd, 2014).

⁸¹ Davies, 5.

⁸² Davies, 6.

The work takes a lot of liberty with the *Alice* story, and Davies keeps only the most well-known elements: Alice dreaming, falling down a rabbit hole, meeting a white rabbit, and interacting with a pack of living playing cards.

Unlike Gamow, Gilmore does not cover the fantastical and explanatory parts in separate chapters. Instead, the fictional narrative is interspersed with foot- and end-notes from the 'real world', which cover several pages for each chapter: 'They should be sufficiently unobtrusive that you may ignore them as you read the story of Alice's adventures, but when you wish to discover the real significance of these adventures, the notes are conveniently to hand.'⁸³ The first half of the book is loosely based on *Alice in Wonderland*, the latter half on *Through the Looking Glass*. However, Alice's experiences are in most cases quite far removed from Carroll's original adventures. Only two characters from *Alice in Wonderland* appear in the book: the White Rabbit, being late, tries to tunnel through a door in chapter 1, and Schrödinger's Cat appears as the Cheshire Cat in chapter 4.⁸⁴ The other chapters introduce original characters, or characters from other well-known stories, such as Ebenezer Scrooge and the Ugly Duckling. The Queen of Hearts, Red Queen, and White Queen, despite being some of the most distinctive and well-remembered of Carroll's characters, do not feature in the nearly-all-male Quantumland. Only the bare bones of the Alice story are preserved: an exploration of a strange and bizarre world seen through the eyes of someone who has just reached the age at which she thought she knew the world. A world which still seems nonsensical, although knowledge of its rules is slowly revealed to Alice via dialogue,⁸⁵ forms an ideal

⁸³ Gilmore, *Alice in Quantumland*, vi.

⁸⁴ Gilmore, 8.

⁸⁵ Gillian Beer, 'Alice in Time', *The Modern Language Review* 106, no. 4 (October 2011): xxxii, <https://doi.org/10.5699/modelangrevi.106.4.XXVII>.

fictional framework for explaining quantum physics. Quantum physics, Gilmore explains, can sound a lot like nonsense, because it is very hard to explain it in terms of things we already know: 'It seems to make nonsense but it works. It is probably safe to say that no-one really understands quantum mechanics so I cannot *explain* but I can tell you how we *describe* what goes on.'⁸⁶ He explains his use of analogy in the preface to his novel:

The way that things behave in quantum mechanics seems very odd to our normal way of thinking and is made more acceptable when we consider analogies to situations with which we are familiar, even though the analogies may be inexact. Such analogies can never be very true to reality as quantum processes are really quite different from our normal experience.⁸⁷

Although Gilmore calls his work an analogy, according to the definition given above, his text offers more than analogy alone: his scientific fantasy can be considered an extended metaphor. The implication is that connections between ideas are more easily made when they relate to a story we already know. Scientifically fantastic stories for adults, such as Abbott's and Gamow's, are usually original stories, so that the reader would encounter new fiction and new scientific concepts at the same time. Gilmore's work, on the other hand, makes use of already known fiction, so that only the scientific content is new to the reader.

Mr Tompkins in Wonderland is much more loosely based on Carroll's works than *Alice in Quantumland*. The Wonderland aspect in Gamow refers to the fact that Mr Tompkins encounters fantastical scale changes and anthropomorphic particles in his dreams. However, a focus on the billiards game in both works brings out several other

⁸⁶ Gilmore, *Alice in Quantumland*, 48. This observation contains a direct quotation from Richard P. Feynman.

⁸⁷ Gilmore, v.

noticeable parallels between *Mr Tompkins in Wonderland* and *Alice in Quantumland*. These parallels show how Gilmore combines the existing narrative of *Alice in Wonderland* with metaphors that have been previously used, and proven successful, in the popular exposition of quantum physics.

Gilmore's and Gamow's works are aimed at similar audiences in terms of age and cultural background, although Gilmore avoids Gamow's gender stereotyping: Alice's ignorance about the world of quantum physics is not attributed to her gender; as in *Alice in Wonderland*, Alice is considered to be such a unique being that she is classified as 'an Alice'.⁸⁸ Reading about a protagonist who is younger than the readers, and who is already known for being curious, will likely make the reader forgive Alice more easily for not understanding something immediately, compared to a protagonist like Mr Tompkins. However, a pace that is too high for the reader to follow, combined with a teenage protagonist who understands everything, can alienate the older reader. Gilmore visibly errs on the side of caution by making Alice frequently state, 'I do not understand', to the point where the narrator notes that 'This seemed to her to be the only thing she ever said.'⁸⁹

In both works, the billiards game is intended to explain the uncertainty principle. Neither Mr Tompkins nor Gilmore's Alice are physically involved in the games: they are observers, who may ask questions, but who may not participate. Compared to Lewis Carroll's Alice, Gilmore's protagonist has much less agency, which is visible from the start: whereas Alice ends up in Wonderland by deliberately running after the White Rabbit, her namesake ends up in Quantumland by tripping over her copy of *Alice in*

⁸⁸ Gilmore, 5.

⁸⁹ Gilmore, 39.

Wonderland and falling into the TV.⁹⁰ In being passive observers, Mr Tompkins and Alice are in a position similar to that of the reader, who observes the fantastical world from the outside.

The second dream in *Mr Tompkins in Wonderland* is titled ‘The Quantum Room’. The physicist introduces his lecture attendees to Ψ , which represents the wavefunction as proposed by Schrödinger, and to a matrix, following Heisenberg’s approach. Confusedly falling asleep at home, Mr Tompkins ‘unexpectedly’ finds himself ‘in a big smoking room with several people in shirtsleeves playing billiards on the central table.’ When one of the players hits the ball, ‘Mr Tompkins noticed to his great surprise that the ball began to “spread out”. [...] It looked as if not one ball was rolling across the table but a great number of balls, all partially penetrating into each other.’⁹¹ The phenomenon is accompanied by illustrations. In *Alice in Quantumland*, the third chapter takes place at ‘The Mechanics Institute’, where Alice upon entering ‘found herself in a large, dark room. [...] In the pool of light was a billiards table, with two figures moving around it.’⁹² The two players are a Classical Mechanic and a Quantum Mechanic; when the Classical Mechanic takes his turn he ‘took careful aim, clearly judging all the angles involved to within a tiny fraction of a degree. At last, he very deliberately played his shot.’⁹³ However, when the Quantum Mechanic plays his shot, he

made a vague stab with his cue. After her previous recent experiences Alice was not really surprised to discover that the ball shot off in every direction at once, so that there was no part of the table where she could say definitely that the ball had not gone, though equally she could in no way say where it actually was.⁹⁴

⁹⁰ Gilmore, 1–2.

⁹¹ Gamow, *Mr Tompkins in Wonderland*, 13.

⁹² Gilmore, *Alice in Quantumland*, 30.

⁹³ Gilmore, 31.

⁹⁴ Gilmore, 32.

Both narratives explain the difference between classical mechanics and quantum physics by representing the uncertainty principle in a billiards game; it is unlikely that Gilmore, a physicist writing in the 1990s, was unacquainted with Mr Tompkins. The billiards game may well have been borrowed directly from Gamow; as the next chapter shows, one can make a different analogy that is more faithful to *Alice in Wonderland* with reference to the Queen of Hearts' croquet game. The fragment works equally well in a narrative that purports to follow *Alice in Wonderland* and in a narrative that has only borrowed its title: the strength of this particular analogy proved more valuable than the overarching *Alice in Wonderland* trope.

Alice in Quantumland aims to explain quantum physics to adult readers by means of a setting taken from a famous children's book. The scientific fantasy here facilitates not only the use of related metaphors and analogies, but also provides a familiar and predictable setting for the reader in which to encounter new concepts. The reader will recognize many characters and the actions with which they are commonly associated; at the same time, Gilmore updates Alice's adventures to keep them appealing to an adult audience by borrowing successful analogies from other scientific fantasies such as *Mr Tompkins*. Making use of a narrative in which the reader expects nonsense and a constantly questioning protagonist facilitates the explanation of even the most bizarre physics.

Conclusion

Scientifically fantastic popularizations constitute a genre separate from both science fiction and fantasy, characterized by their didactic intention and use of real science

conjoined with fantastic elements. Their use of a fantastical setting leads to an estrangement which can make it easier for the author to explain complex, abstract scientific concepts. The fantastical setting offers an obviously fictional environment that can be used as a source of easily comprehensible metaphors and analogies.

In the works discussed here, the fantastical world devised by one author turns out to provide a useful framework for other authors intending to popularize later scientific developments or different fields. Even though both the scientific and the fictional content need updating, the original narratives have often gained enough traction to warrant connecting to an entirely new work. Whereas Russell Stannard chose to place Mr Tompkins himself in the twenty-first century, Dionijs Burger and Ian Stewart chose as their protagonists twentieth- and twenty-first-century descendants of *Flatland's* A. Square; the Alice of *Alice in Quantumland* has been reading Carroll's work at the start of the book, and Gilmore borrowed allegories from Gamow. The familiar narrative framework is left intact, promising to the reader a modern, updated version of a work that in a previous generation was enormously popular and widely enjoyed. Familiarity, then, is an important force driving public engagement with science, not merely at the level of individual explanations in the work, but also in the wider cultural context in which the work is produced.

The success of the works discussed in this chapter, and the repeated re-use of their fantastic worlds, shows that the scientific fantasy can be a useful form of popularization. Although as a form it is more often associated with nineteenth-century writing and children's books, it offers useful possibilities for connecting directly to current science. As contemporary science grows stranger and stranger, the gap between the world humans perceive and the world science unravels increases, and fantasy seems

to continue to be able to bridge this gap. Works that manage to do so show the reader that metaphor, analogy and allegory are useful tools in the communication of scientific knowledge, thus demonstrating that these rhetorical devices constitute an essential part of science popularization.

Chapter Four: Popularizations of Quantum Mechanics for Children

Introduction

Since their conception in the eighteenth century, science books for children have been based on practical and tangible elements alongside textual explanations: they rely on illustrations and often contain experiments for children to perform. The inclusion of these two elements facilitates affective engagement with the child; however, popularizations of quantum physics aimed at children encounter difficulties in creating such engagement, due to the impossibility of devising child-friendly quantum physics experiments. The ungraspably small scales involved also hinder the creation of accurate yet engaging illustrations. Having no recourse to images and experiments is a major hindrance for science popularizers writing for children, since, as cultural historian Aileen Fyfe indicates,

for a young audience, it was vital for writers to [...] provide clear illustrations. It was also crucial to blend the instruction with amusement, for while adults might be willing to persevere in the name of increased knowledge, bored children would be more likely simply to close the book.¹

Quantum physics books for children resolve this issue by presenting a scientifically fantastic story. The first of such books followed more than a decade after the surge of interest in quantum physics among adult readers in the 1980s discussed in Chapter 1. This chapter consists of three case studies of children's books that cover quantum physics, and the way in which these rely on the scientifically fantastic story, rather than

¹ Aileen Fyfe, 'Introduction to Science for Children', in *Evenings at Home, or The Juvenile Budget Opened I-III*, by John Aikin and Anna Laetitia Barbauld, Science for Children 1 (1809; repr., Bristol: Thoemmes Press, 2003), xi–xxii, p. xi–xii.

on experiments and realistic illustrations, in order to educate readers about this complicated topic. The scientifically fantastic story serves as both a source for illustrations and a narrative framework for the exposition. All of the children's books I have been able to identify that discuss quantum physics are written in this narrative form, discussed in the previous chapter: Russell Stannard's *Uncle Albert and the Quantum Quest* (1994), which is the third instalment in Stannard's *Uncle Albert* series (1989-1998);² the George Greenby series written by Lucy and Stephen Hawking (2007-present);³ and Otto Fong's *The Quantum Bunny* (2015), which is the fifth instalment in the series *Sir Fong's Adventures in Science* (2008-present).⁴ The works are aimed at children who will not yet have encountered the topic in a school setting: ages 10+ for Stannard, 8-12 for Hawking and Hawking, and under-16 for Fong. A discussion of Chris Ferrie's *Quantum Physics for Babies* (2013), a highly popular board book on quantum physics for pre-literate children, is omitted as the work does not contain enough text or narrative to warrant comparison with the books discussed in this chapter.⁵

As discussed in the Introduction, the little research in literature and science that does touch upon popular science for children has largely neglected works that were written in the twentieth and twenty-first century. In this chapter, I investigate the strategies used to communicate a contemporary, advanced scientific field to children. I will

² Stannard, *Uncle Albert and the Quantum Quest*.

³ Hawking and Hawking, *George's Secret Key to the Universe*, henceforth *Secret Key*; Lucy Hawking and Stephen Hawking, *George's Cosmic Treasure Hunt* (London: Doubleday, 2009), henceforth *Cosmic Treasure Hunt*; Lucy Hawking and Stephen Hawking, *George and the Big Bang* (London: Doubleday, 2011), henceforth *Big Bang*; Lucy Hawking and Stephen Hawking, *George and the Unbreakable Code* (London: Doubleday, 2014), henceforth *Unbreakable Code*; Lucy Hawking and Stephen Hawking, *George and the Blue Moon* (London: Doubleday, 2016), henceforth *Blue Moon*. A sixth instalment, *George and the Ship of Time*, has been announced for May 2018.

⁴ Fong, *The Quantum Bunny*.

⁵ Chris Ferrie, *Quantum Physics for Babies* (2013; repr., Naperville, IL: Sourcebooks, 2016).

examine to what extent the science fantasy format continues to be used in the present day, and analyse the choices made concerning form, genre and scientific content, in relation to the targeted audiences of the works and the overall aims of the authors.

The Introduction briefly referred to the work of Alice Bell, whose 2008 PhD thesis is, to my knowledge, the only book-length study of twentieth- and twenty-first-century popular science for children.⁶ Bell focuses on the extremely popular *Horrible Science* series by Nick Arnold, illustrated by Tony de Saulles (2005-present). The *Horrible Science* books are aimed at a slightly younger age group than the works discussed in this chapter, '7-11-year-olds'; its methods and approaches are entirely different.⁷ The *Horrible Science* books are not scientific fantasies; instead, they present their contents in an amalgamation of short stories, comic strips, factual explanations, quizzes, and experiments. Bell notes that the series is focused on giving the readers miscellaneous facts around a broad theme, which they are encouraged to go and show off to their peers.⁸ These books therefore have little room to build up an extended narrative which can slowly construct an explanation of a complex scientific topic: quantum physics does not appear in any of the books. A key selling point of the series is the idea that science is 'horrible', meaning disgusting or scary, and that these books provide an insight into the 'horrible' side of science that dull adults such as parents and schoolteachers will not allow children to engage with. The works discussed here, on the other hand, are marketed to appeal to parents looking for engaging reading material for a precocious

⁶ Bell, 'Science as Pantomime'.

⁷ Bell, 2.

⁸ Bell, 93.

child: the *George* books, with their glossy hardcovers and colour pictures, are a particularly notable example.

Bell observes that ‘the simplifications of children’s science are often several decades, if not whole centuries, behind current research.’⁹ She argues that these forms of simplification do not necessarily follow from the need to simplify very complex science; they are also shaped by cultural assumptions. Twenty-first-century children’s science books such as *The Dangerous Book for Boys*, she argues, exude a sense of nostalgia toward the pre-digital era.¹⁰ A similar nostalgia, albeit not aimed at the digital, can be seen in the popularizations discussed in this chapter. These works must ground themselves in a twentieth- or twenty-first-century context, because they include the most up-to-date research, and explicitly negotiate the necessary role of the digital in an age in which this science is researched. However, the fiction on which their narratives are based harks back to a very distant past – in Otto Fong’s case, to a novel that is nearly four hundred years old.

Bell concludes that the *Horrible Science* series engages in what she calls ‘irreverent deference’: applying ‘irreverence in the face of high-status knowledge[,] apparently laughing at the pomposity of thinking we know anything, yet, at the same time, using this irreverence to delight in the processes of knowing.’¹¹ She identifies this irreverence as a trend in twenty-first-century science communication, including popular TV shows such as *QI* (2003-present) and *Brainiac* (2003-2008). Surprisingly, this irreverent deference seems to be absent from all quantum physics popularizations. The

⁹ Bell, 64.

¹⁰ Bell, 244.

¹¹ Bell, 10.

science fantasies, for adults and children alike, even display an explicit reverence for older stories. Even the most whimsical of popularizations, the aforementioned *Quantum Physics for Babies*, never pretends to look down on any aspects of science. Similarly, Chad Orzel's *How to Teach Quantum Physics to your Dog* sounds irreverent, but never laughs at 'high-status knowledge'. *Horrible Science* makes fun of authority figures such as parents, teachers, and scientists, and selects those scientific topics that are delightful because of the way they undermine the 'boring' science that is taught in school, by being gross, messy, or dangerous. Orzel never pretends to undermine scientific authority: the narrator is a physicist and draws on his authority; the only group towards whom this book might be considered irreverent is the readership, as they are made to adopt the perspective of a dog.

Traditions in Science Writing for Children

Science writing for children in England started to flourish in the late eighteenth century, developing from a tradition which is considered to have started with the author/publisher John Newbery around the 1740s-50s.¹² From his hand comes one of the earliest science popularizations for children in English: *The Newtonian System of Philosophy; Explained by Familiar Objects, in an Entertaining Manner, For the Use of Young Ladies and Gentlemen* (1761), written under the pseudonym Tom Telescope.¹³ The contents are presented as lectures given by the boy Tom to his peers, which anticipates the

¹² Jonathan R. Topham, 'Publishing "Popular Science" in Early Nineteenth-Century Britain', in *Science in the Marketplace: Nineteenth-Century Sites and Experiences*, ed. Aileen Fyfe and Bernard V. Lightman (Chicago: University of Chicago Press, 2007), 135–63, p. 143.

¹³ Tom Telescope, *The Newtonian System of Philosophy; Explained by Familiar Objects, in an Entertaining Manner, For the Use of Young Ladies and Gentlemen*, 1761. New Improved ed. (London: Ogilvy and Sons, 1798).

dialogue form that in the late eighteenth and early nineteenth century would be taken up in popular science works such as *Evenings at Home* and Jane Marcet's *Conversations*.¹⁴ The dialogue and the scientifically fantastic story were the two prevalent forms in science writing for children in the early nineteenth century.¹⁵ Although Myers argues that the dialogue format was 'already old-fashioned' by the mid-nineteenth century,¹⁶ it is noticeably present in contemporary popular science and fiction: in both genres, dialogue is used to convey scientific concepts from scientist to non-scientist or child protagonists. Arabella Buckley's *The Fairy-Land of Science* (1879) and its sequel *Fairy-Land through Magic Glasses* (1890) are examples of early scientific fantasy.¹⁷ The use of fiction in popular science in this time period is discussed at length in Melanie Keene's *Science in Wonderland*.¹⁸ Little has been written on the dialogue and the scientific fantasy in twentieth- and twenty-first-century works for children, however, although both elements continue to be prevalent.

In the nineteenth century, science popularization for children was dominated by female authors such as Jane Marcet, Arabella Buckley, and Margaret Gatty, whose works were considered appropriate entertainment material for girls and women. In

¹⁴ John Aikin and Anna Laetitia Barbauld, *Evenings at Home, or The Juvenile Budget Opened I-III*, Science for Children 1 (1792–1796; repr., Bristol: Thoemmes Press, 2003); Jane Marcet, *Conversations on Chemistry*, ed. Bernard Lightman (1806; repr., London: Thoemmes Continuum, 2004); Jane Marcet, *Conversations on Political Economy: In Which the Elements of That Science Are Familiarly Explained* (London: Longman, Hurst, Rees, Orme, and Brown, 1816); Jane Marcet, *Conversations for Children, on Land and Water* (London: Longman, Orme, Brown, Green, & Longmans, 1838).

¹⁵ Aileen Fyfe, 'Young Readers and the Sciences', in *Books and the Sciences in History*, ed. Marina Frasca-Spada and Nicholas Jardine (Cambridge: Cambridge University Press, 2000), 276–90.

¹⁶ Greg Myers, 'Science for Women and Children: The Dialogue of Popular Science in the Nineteenth Century', in *Nature Transfigured: Science and Literature, 1700-1900*, ed. John Christie and Sally Shuttleworth (Manchester: Manchester University Press, 1989), 171–200, p. 171.

¹⁷ Arabella B. Buckley, *The Fairy-Land of Science* (London: Edward Stanford, 1879), <http://www.gutenberg.org/ebooks/5726>; Arabella B. Buckley, *Through Magic Glasses and Other Lectures* (London: Edward Stanford, 1890), <https://www.gutenberg.org/files/37589>.

¹⁸ Keene, *Science in Wonderland*.

the nineteenth century, readerships were more strictly segregated according to gender than according to age, a divide Rachel Falconer summarizes thus: ‘domestic novels were read by girls and women, while adventure novels [...] were read by boys and men’.¹⁹ From the twentieth century onwards, popularizations became divided along an adult/child age boundary rather than a gender boundary. Popular science authors, now usually men, would often write for both age groups: of the authors analysed in this chapter, Otto Fong is the only one who has not written popular science for adults.

Children’s books that aim to explain a very specific, advanced subfield of science tend to be rare. Most science books for children that were written in the late twentieth and early twenty-first century are general introductions that roughly fall into two categories. Popular science series, such as the aforementioned *Horrible Science* series, are arranged along the lines of school subjects. The other category aims to introduce the concept of ‘science’ and the scientific method: one example is *Dr Art’s Guide to Science* by the US science popularizer Art Sussman. Books from either of these two categories generally do not engage with quantum physics. Sussman states explicitly that he will avoid this topic: ‘I will not even try to explain quantum mechanics in this book. [...] In this book, we are learning the basics of the science game. Quantum mechanics is for very advanced players.’²⁰ The scientific fantasy is also used in such general introductions to science. The *Frank Einstein* series by John Scieszka and Brian Briggs, for instance, opens with the boy Frank applying ‘as he always does, the scientific method he

¹⁹ Rachel Falconer, *The Crossover Novel: Contemporary Children’s Fiction and Its Adult Readership* (New York: Routledge, 2009), 13.

²⁰ Art Sussman, *Dr. Art’s Guide to Science: Connecting Atoms, Galaxies, and Everything in Between* (San Francisco: Jossey-Bass, 2006), 77.

learned from his Grampa Al.’²¹ This series explains scientific concepts and methods within a fantasy storyline based of course on Mary Shelley’s *Frankenstein* (1818): a lightning strike causes the robot Frank is building to come to life, after which this robot builds another one.²² Here, too, the scientific fantasy is used to communicate concepts that are difficult to convey through experiments: in this case, to explain the scientific method, in which failure is as important as success in experimentation.

Alice in [Science Pun]Land

The previous chapter discussed Robert Gilmore’s *Alice in Quantumland* (1994), a popularization for adults that made use of an Alice in Wonderland setting. That same year also saw the publication of the first children’s popularization of quantum physics, Russell Stannard’s *Uncle Albert and the Quantum Quest*, which also relied on *Alice in Wonderland*. Stannard describes his intended audience as ‘10+ years and more’; the back cover of *Uncle Albert and the Quantum Quest* displays two reviews by ‘Christian Rodriguez, aged 11’ and ‘Jennie Pope, aged 13’. Gilmore’s and Stannard’s Alice-inspired books were reviewed together in *New Scientist* at the time; the reviewer, physicist George Lafferty, confirmed that ‘The narrative [of *Uncle Albert and the Quantum Quest*] is [...] clearly aimed at children, perhaps aged ten and upwards. But here I have to come clean – I thoroughly enjoyed it, and I’m over twenty-one.’ On the other hand, ‘Alice in Quantum Land [*sic*], as may be inferred from the presence of an index, is a much more

²¹ Jon Scieszka and Brian Biggs, *Frank Einstein and the Antimatter Motor* (London: Amulet Books, 2014), 2.

²² Mary Wollstonecraft Shelley, *Frankenstein; Or, The Modern Prometheus* (London: Lackington, Hughes, Harding, Mavor, & Jones, 1818), <https://www.gutenberg.org/ebooks/84>. The moral aspect of the scientist handling forces beyond his control and creating a monster is lost in adaptation, as the two robots become Frank’s good friends.

weighty affair.²³ These two popularizations of quantum physics are vastly different works, yet both build on the same nineteenth-century children's book.

Countless popularizations of science, covering disciplines from biology to astrophysics, have made use of *Alice's Adventures in Wonderland* and *Through the Looking-Glass*. In the nineteenth century in particular, many science writers may simply have wanted to partake in the fame attached to these books: thousands of readers would associate a book with 'Wonderland' in the title with their new favourite book. George Gamow continued this approach in the twentieth century by titling his first popularization *Mr Tompkins in Wonderland* despite its having nothing to do with *Alice's Adventures in Wonderland*. Recent adaptations of *Alice* also follow the nineteenth-century pattern of using fairy tales in popular science to show that the world as explained by science can be even more wondrous than fiction. As the title of Melanie Keene's work on nineteenth-century popularization, *Science in Wonderland*, suggests, the science component in Carroll's fantasy was recognized from the moment it was published:

Ever since its inception, Carroll's *Alice* had been a very influential commentary on the relationships between scientific reasoning and fantastical imagining, didacticism and childish curiosity, the natural world and its peculiarities, and the strangeness lurking just beneath the surface of (or on the other side of) the quotidian.²⁴

Keene shows that it did not take long before the first science popularizations for children based on *Alice in Wonderland* were published. Not all of these adaptations were received well: one illuminating example of a failed adaptation is Albert and George

²³ George Lafferty, 'Review: The Importance of Being Alice', *New Scientist*, 21 May 1994, <https://www.newscientist.com/article/mg14219264-500-review-the-importance-of-being-alice/>.

²⁴ Keene, *Science in Wonderland*, 105.

Gresswell's *The Wonderland of Evolution* (1884).²⁵ Keene, describing the book as ‘just one of the post-*Alice* books which capitalized on the popularity of all things “wonderland”’, points out that the book met with mixed reviews: she quotes the *Glasgow Herald*, whose reviewer assumes that the work was influenced by *Alice in Wonderland*, but notes that

there is little to justify our supposition beyond the name and a painful effort now and then apparent to be grotesque, as when we are introduced to a party of molluscs drinking tea and brandy [...] We fancy the authors mean to be funny, but we only find them silly.²⁶

This work shows that authors came to the Alice story for two reasons: most importantly, the potentially lucrative connection to Lewis Carroll’s immensely popular books, and secondly, to introduce an element of humour, which in this case fell flat.

Their success in the nineteenth century, however, does not explain why the *Alice* books are still such a popular source for scenarios and analogies to explain science to both children and adults in the twenty-first century, when much of the book’s contents – including nearly all of the parody poems – have become outdated to the point that new readers no longer recognize most of the jokes.²⁷ Instead, science popularizers continue to use the *Alice* books because of their adaptability, their use of logic and nonsense, and their recognizable characters.

One of the tropes that science popularizations borrow most often from Carroll is that of scale change. Alice’s changes in size are such a memorable and central element

²⁵ Albert Gresswell and George Gresswell, *The Wonderland of Evolution* (London: Field & Tuer, Ye Leadenhalle Presse, & Co., 1884).

²⁶ Keene, *Science in Wonderland*, 118, 123.

²⁷ Martin Gardner’s *The Annotated Alice* is for a large part dedicated to explaining the now-obscure jokes, and gives the originals of the songs and poems so that contemporary readers can appreciate the parodies. Lewis Carroll, *The Annotated Alice: The Definitive Edition*, ed. Martin Gardner (London: Penguin, 2001).

in the narrative of *Alice's Adventures in Wonderland* that neurology has adopted the term 'Alice in Wonderland syndrome' for a visual hallucination in which the patient observes their surroundings to be much bigger or smaller than they actually are.²⁸ Alice's growing and shrinking does not occur in *Through the Looking-Glass*: most popularizations borrow characters from both works, yet the events they adopt are usually taken from the first book alone. Russell Stannard is consistent in only including characters from *Alice's Adventures in Wonderland*, and none from *Through the Looking-Glass*, even though the works are rarely read or adapted separately: the Disney adaptation, for instance, takes both books and turns them into one film.²⁹ Robert Gilmore does combine both works in his popularization: he includes references to Humpty Dumpty in a discussion of definitions, and lets Alice run while staying in one place with the Quantum Mechanic, who takes the place of the Red Queen.

Both size and time are controllable in Carroll's Wonderland, although Alice is the only one capable of size changes, through eating and drinking; one could control Time by befriending him, but Alice does not attempt to do this. Alice never witnesses another creature change its size, even though other metamorphoses take place, such as the Duchess's baby turning into a pig and the Cheshire Cat appearing and disappearing at will. As soon as the Caterpillar has helped her find out how to control her size, Alice uses this power to satisfy her curiosity: she makes herself large enough to attend the Mad Tea-Party, and takes the key off the glass table before shrinking herself again to fit through the door leading to the Queen of Hearts's garden.³⁰ This unique ability of

²⁸ J. Todd, 'The Syndrome of Alice in Wonderland', *Canadian Medical Association Journal* 73, no. 9 (1 November 1955): 701–4.

²⁹ Clyde Geronimi and Wilfred Jackson, *Alice in Wonderland* (Walt Disney Productions, 1951).

³⁰ Carroll, *The Annotated Alice*, 69, 70, 81.

Alice to control her size ‘to put herself into an ideal functional relation with the physical world around her’ is nearly always taken up in popularizations as a way for the protagonist to learn about the world.³¹ Stannard’s protagonist, Gedanken, exercises control over her learning process by controlling her size: she knows from the start that the bottle marked ‘Drink Me’ will make her smaller; when she wants to look at the atoms up close, she remembers this bottle and uses it to shrink to her desired size.³² Alice is thus an ideal model for the curious child that wants to learn about science, as she is not taken by the hand and led to the answers, but is in control of her engagement and adapts to her surroundings.

Written by a ‘professional logician’, the *Alice* books are full of logic puzzles and paradoxes.³³ These provide the most obvious bridge between the *Alice* books and quantum physics, a field that consists of seemingly paradoxical observations and theories. As Keene points out, in modern physics, ‘as Alice’s trip to Wonderland had revealed, logic could indeed now be stranger than imagination, truth stranger than fiction.’³⁴ One can see the attraction these books might have for popularizers who liked them so much *as scientists*, rather than because the books are the most ideal vehicles for communicating science. To Carroll, who was already famous for writing pamphlets about the University of Oxford that displayed ‘the same ability to parody arguments and drive them well beyond their logical conclusions’,³⁵ the play with logic in the *Alice* books reflected the way in which he combined jest and rigour in his life as a mathematician. His

³¹ Beer, *Alice in Space*, 42.

³² Stannard, *Uncle Albert and the Quantum Quest*, 8, 25.

³³ Beer, *Alice in Space*, 45.

³⁴ Keene, *Science in Wonderland*, 195.

³⁵ Keith Hannabuss, ‘The Mid-Nineteenth Century’, in *Oxford Figures: 800 Years of the Mathematical Sciences*, ed. John Fauvel, Raymond Flood, and Robin J. Wilson (New York: Oxford University Press, 2000), 187–201, p. 196.

textbooks could look as seemingly flippant as his fiction: writing a treatise about Euclid's *Elements*, 'attempting to reach a wider audience, Dodgson cast his book as a play in four acts'.³⁶ Combining serious science with entertainment, an essential combination for science popularizers, was not new to Dodgson when he first donned his Carroll pseudonym.

Carroll's engagement with nonsense provides another source of analogies for quantum physics. Stannard points out that advanced modern physics can and should be communicated to children because they can handle apparently nonsensical concepts better than adults:

It was Einstein himself who once dismissed commonsense as 'that layer of prejudice laid down in the mind before the age of 18'. This gives further reason why one's first acquaintance with modern physics should occur as early as possible—before one's thinking has become too set in its ways.³⁷

The way in which the *Alice* books engage with nonsense enables the young reader, who is assumed to be still flexible enough to accept a bizarre premise and follow it through, to see the strangeness in everyday life and science:

The last level of metaphor in the *Alice* books is this: that life, viewed rationally and without illusion, appears to be a nonsense tale told by an idiot mathematician. At the heart of things science finds only a mad, never-ending quadrille of Mock Turtle Waves and Gryphon Particles.³⁸

This combination of logic and nonsense provides fertile ground for explaining science in a humorous way. Susan Stewart points out that inversion of the status quo is one of

³⁶ Robin J. Wilson, *Lewis Carroll in Numberland: His Fantastical Mathematical Logical Life. An Agony in Eight Fits* (London: Allen Lane, 2008), 93.

³⁷ Stannard, 'Communicating Physics through Story', 31.

³⁸ Martin Gardner, 'Introduction to The Annotated Alice', in *The Annotated Alice: The Definitive Edition*, by Lewis Carroll (London: Penguin, 2001), xiii–xxiv, p. xxiii.

the oldest forms of humour, and the *Alice* books offer many such examples of inversion.³⁹ As the reader of the *Alice* books is familiar with so many different forms of inversion, this trope can be used to explain scientific concepts that at first sight seem to invert the scientific status quo. However, popularizations that use the *Alice* setting face a serious potential problem: they need to convince the reader that, unlike the *Alice* books, the content they present, however humorously conveyed, is *not* nonsense. Thus, the popularizer runs into the problem Dodgson himself had encountered: mixing real science with whimsy may lead to the science being ignored.

The character of Alice, however, can bridge this gap between nonsense and science. Alice is an extremely sensible girl, who remembers not only her own lessons, but even the ones given to her older brother. She does not drink anything carelessly without checking if it is marked 'poison'. She is an ideal model of a child who performs scientific investigations. She thinks events through logically, and is often the only character to do so: "It's the oldest rule in the book," said the King. "Then it ought to be Number One," said Alice.⁴⁰ She shows how important logical reasoning can be in a seemingly nonsensical world.

Alice navigates this world by means of dialogue: 'the oral trumps the written' in Carroll's books.⁴¹ Alice engages in dialogues with all the characters she encounters, questioning her surroundings in order to attempt to make sense of them. Although all these characters are adults, or adult animals, she does not always take their answers for granted, and offers explanations of her own. This dialogic aspect of the *Alice* books,

³⁹ Susan Stewart, *Nonsense: Aspects of Intertextuality in Folklore and Literature* (Baltimore: Johns Hopkins University Press, 1979), 67.

⁴⁰ Carroll, *The Annotated Alice*, 125.

⁴¹ Beer, *Alice in Space*, 35.

too, translates well to popular science. In Stannard's books, Gedanken learns from dialogues with her uncle, and offers observations in return, which confirm his conjectures. Similarly, in the Hawkings' books, the child protagonists George and Annie exchange their observations for fundamental scientific knowledge through conversations with the scientist Eric.

In the nineteenth century, the new scientific ideas that were expounded through references to *Alice in Wonderland* included non-Euclidean geometry, a field in which *Flatland*, discussed in the previous chapter, was most influential.⁴² Gillian Beer points out that Charles Dodgson the mathematician defended the idea of an Euclidean world, but Lewis Carroll the writer plays with different interpretations of space and time, in which multiple dimensions as well as multiple speeds and directions in which time can run are possible.⁴³ Such a world, in which even the most unbelievable new scientific ideas can be observed, lends itself eminently to adoption in popular science for children.

The ease with which the Alice books may be relied on for the communication of modern physics is further facilitated by the fact that some of Carroll's creations have become stock metaphors within science. Gillian Beer points to the Red Queen hypothesis and the aforementioned Alice in Wonderland syndrome as the best-known examples from biology.⁴⁴ In 1976, David Mermin embarked on 'a long-running campaign to see if I could make the silly word "boojum" an internationally accepted technical

⁴² Keene, *Science in Wonderland*, 80.

⁴³ Gillian Beer, 'Alice in Time', *Nature* 479, no. 7371 (2011): 38–39.

⁴⁴ Beer, *Alice in Space*, 1.

term.⁴⁵ Carroll's nonsense word from *The Hunting of the Snark* indeed became accepted as the term for a geometric pattern in superfluidity. In quantum physics, the 'Quantum Cheshire Cat' is a term introduced in 2013 as a metaphor in which 'the Cat is a photon, while the grin is its circular polarization' – the photon and its polarization being observed in different places.⁴⁶ The use of an Alice setting in popularization may therefore result from scientist-authors falling back on the fictional work they know best, suggesting an element of intellectual laziness in spite of the highly imaginative contents and specific explanations in the books.

One of the CERN experiments, ALICE: A Large Ion Collider Experiment, brings together the popularity of Alice metaphors in science and Alice's lasting popularity with the general public. The logo of the experiment has a little blonde girl in a blue dress standing with her back to us on the E. In the 'Children's Corner' of the ALICE website, a comic is available for download which explains the experiment to children – the intended age of these children is not indicated – through a story that starts with a girl called Alice falling down a rabbit hole and landing in the underground facility at CERN.⁴⁷ Notably, although the ALICE logo shows Tenniel's/Disney's Alice, the Alice in the comic book is modernized: she has short brown hair, trousers, and a crop top. Making use of a familiar narrative setting, the comic explains a highly specialized scientific investigation to children.

⁴⁵ N. David Mermin, 'Writing Physics: Knight Distinguished Lecture in Writing in the Disciplines', Cornell University Laboratory of Atomic and Solid State Physics, 28 August 2012, <https://web.archive.org/web/20120828183555/http://www.lassp.cornell.edu/~cew2/KnightLecture.html>.

⁴⁶ Yakir Aharonov et al., 'Quantum Cheshire Cats', *New Journal of Physics* 15, no. 11 (2013), <https://doi.org/10.1088/1367-2630/15/11/113015>.

⁴⁷ Jordi Boixader, *Alice and the Soup of Quarks and Gluons* (Geneva: CERN, 2004), http://aliceinfo.cern.ch/Public/en/Chapter4/E_AliceBD.pdf.

Uncle Albert and the Quantum Quest takes a more irreverent approach to the Alice trope, although it still relies on the reader's familiarity with the story: Stannard adds a metafictional layer in which his protagonist responds negatively to finding herself in the role of Alice. The work is the third instalment in a series he began in 1989, which focuses on the young girl Gedanken and her physicist uncle, Albert.⁴⁸ Uncle Albert is, of course, Albert Einstein, who is famous for his thought experiments: his explanation of special relativity by means of a passing train in his 1920 popular work became a stock textbook explanation;⁴⁹ in 1930, he invented the 'clock in the box' thought experiment to question Heisenberg's uncertainty principle;⁵⁰ and as mentioned in Chapter 1, Schrödinger's cat was developed in an exchange of letters between Schrödinger and Einstein. The name Gedanken is a German noun, a masculine plural, meaning 'thoughts': *Gedankenexperiment* means 'thought experiment' and is the term Einstein used. On the very last page of *Quantum Quest*, Stannard explains how the real Einstein performed thought experiments: 'In his native German language, they were called "gedanken experiments" [*sic*].'⁵¹ Whether the reader knew this meaning before this point or not, the name marks Gedanken out as unusual. Identification with the character is complicated by giving her a German noun for a first name, although a name that is not gendered female might slightly facilitate identification for male readers; the

⁴⁸ The trope of having a famous scientist family member named Albert is also taken up in the *Frank Einstein* series, although Scieszka makes it clear that this Albert is not the one who came up with the theories of relativity: 'I have to tell you, I am not *that* Einstein. But over the years I *have* dabbled in a bit of physics.' Scieszka and Biggs, *Frank Einstein and the Antimatter Motor*, 44.

⁴⁹ Albert Einstein, *Relativity: The Special and the General Theory*, trans. Robert W. Lawson (1920; repr., New York: Penguin Books, 2006), 23.

⁵⁰ Michael T. Stuart, 'Taming Theory with Thought Experiments: Understanding and Scientific Progress', *Studies in History and Philosophy of Science Part A* 58 (August 2016): 24–33, <https://doi.org/10.1016/j.shpsa.2016.04.002>, p. 27.

⁵¹ Stannard, *Uncle Albert and the Quantum Quest*, 142.

Dutch translation rejects this approach and calls her *Sterre* – an existing female Dutch name meaning ‘star’.⁵² The German translation, on the other hand, adopts Stannard’s approach: in German, she is called *Memory*.⁵³

Uncle Albert can make his thought experiments come to life: in each book, *Gedanken* crawls into his thought bubbles and enacts the thought experiment from there. This episodic approach, with a different thought experiment on each topic, lends itself well to sequelization. In this particular episode, *Gedanken* is extremely unhappy, as she climbs into her Uncle Albert’s thoughts, to find that the thought experiment she is part of is based on *Alice in Wonderland*:

‘I can’t believe it,’ she thought to herself. ‘How old-fashioned can you get? *Alice in Wonderland*, for goodness’ sake!’

She racked her brains. What actually happened in *Alice in Wonderland*? It was ages since she had read it – or more like skimmed it. Frankly, it wasn’t one of her favourite books.⁵⁴

Eventually, *Gedanken* does come to appreciate the quantum mechanical *Wonderland*, and befriends the White Rabbit, who is the Chief Scientist of the Queen of Hearts. Although she remembers little about the *Alice* books herself, the readers are assumed to recognize the White Rabbit, the Queen of Hearts, and famous quotations such as ‘Off with his head!’ Stannard encourages his readers to familiarize themselves again with the *Alice* books: the narrative implies that the books are part of a shared cultural capital the reader is expected to know, but also to enjoy. If *Gedanken* ends up enjoying her time in *Wonderland* despite her initial prejudice, so will the reader.

⁵² Judith Eiselin, ‘Een duik in het kwantumraadsel (Diving Into the Quantum Riddle)’, *NRC*, 6 September 2002, <https://www.nrc.nl/nieuws/2002/09/06/een-duik-in-het-kwantumraadsel-7604611-a1353085>.

⁵³ Russell Stannard, *Durch Raum und Zeit mit Onkel Albert: eine Geschichte um Einstein und seine Theorie*, trans. Ulli Günther and Herbert Günther (Frankfurt am Main: Fischer, 2005).

⁵⁴ Stannard, *Uncle Albert and the Quantum Quest*, 7.

The storyline of *Uncle Albert and the Quantum Quest* ends with a chapter based on the Tea Party in *Alice's Adventures in Wonderland*. In Chapter 9, 'The Mad Scientists' Tea Party', Gedanken is invited to a dinner party with real scientists who are attempting to solve the mysteries of the quantum world. This chapter presents a miniature conflict narrative, in which the state of quantum physics in the 1930s is recreated. Attending the dinner are Werner (Heisenberg), Niels (Bohr), Max (Planck), Louis (de Broglie), Erwin (Schrödinger), and another Max (Born), who are all referred to by their first names only. There are no notes or comments to help readers identify the last names of these figures: neither the child reader nor most adults will be able to recognize all of them. Taking away their famous last names makes the scientists approachable, and more equal to Gedanken, whose last name the reader does not know either. At the dinner party, Gedanken takes an immediate liking to 'the nice man Niels', who shares his pudding with her.⁵⁵ But then a conflict breaks out over the Uncertainty Principle:

They were halfway through the main course, when Niels leant forward.

'So, Albert, any more bright ideas for getting round Werner's Uncertainty Principle?' he asked with a grin.

[...] 'I'll come up with something soon, you see if I don't.'

'No you won't,' said Werner. 'I bet you any money you like.'

That was how the row began. Well, not exactly a row. But the conversation suddenly became very heated. They were clearly carrying on an argument they must have started earlier at the conference. They seemed to have completely forgotten Gedanken was there.⁵⁶

Gedanken then interrupts with a question of her own: 'Suppose the electron is just sitting out there in empty space doing nothing. [...] What is it *then*?'⁵⁷ The physicists now

⁵⁵ Stannard, 107, 113.

⁵⁶ Stannard, 109.

⁵⁷ Stannard, 110.

burst into an argument regarding the measurement problem: the question of whether the wave- and particle-like nature is inherent in the electron or comes into being upon the making of a measurement. Both of these conflicts, Einstein's opposition to the uncertainty principle and the measurement problem, precede the creation of the various interpretations of quantum physics that are present in popular science books for adults. Einstein, who died in 1955, did not live to see either the conscious collapse or the many-worlds interpretation being formed; *Uncle Albert and the Quantum Quest* reflects the initial stages of the measurement problem during Einstein's life that later led to the formulations of these interpretations. The young reader is shown that the great minds behind quantum physics do not know everything yet, encouraging the reader towards a potential future as a physicist; what this book does not tell them is that some of these issues, such as Einstein's objection to the uncertainty principle, have now been disproven.

Russell Stannard attributes the success of *Uncle Albert and the Quantum Quest*, which spent a month at the top of the children's bestsellers list, partly to his use of the *Alice in Wonderland* story. This format turned out to be an effective form of science communication: 'Developmental testing of the books prior to their publication revealed that the children not only enjoyed the story format, but also learned a considerable amount of physics from them.'⁵⁸ He reminds his readers that his books can also be enjoyed as novels: 'when the first tale in the series, *The Time and Space of Uncle Albert*, was published in 1989, it was shortlisted for the Whitbread Children's Novel of the Year, as well as the Children's Science Book Prize.' He emphasizes that modern physics

⁵⁸ Stannard, 'Communicating Physics through Story', 32.

is easily adaptable to a story format because of the special fascination it stirs in the reader, more so than ‘more mundane physics—of the National Curriculum type’.⁵⁹

Stannard, citing educational theorists such as Piaget, argues that successful popular science works all adhere to one main principle: they must present their content in a concrete, rather than formal, manner, presenting the effects first before explaining the axioms that underlie them. He claims that such an approach is essential even for adults, because recent research in education has suggested that ‘possibly more than half the adult population *never* reaches formal operations.’⁶⁰ Stannard’s argument partly explains the success of the science fantasy form: it presents the effects of certain operations first, in a fantasy setting, before the operations themselves are explained.

Hawking, Hawking, and George

Fiction author Lucy Hawking and her father Stephen Hawking have co-authored a series of scientific fantasy books for children about a boy called George.⁶¹ In the first instalment, *George’s Secret Key to the Universe* (2008), George Greenby discovers that he has new neighbours: the scientist Eric, clearly modelled on Stephen Hawking, and his daughter, Annie.⁶² Together, George and Annie go on adventures across the universe aided by Eric’s computer Cosmos, who is sentient and can open portals to distant parts of the universe.⁶³ Much like George Gamow’s and Robert Gilmore’s scientific fantasies,

⁵⁹ Stannard, 32.

⁶⁰ Stannard, 33.

⁶¹ Lucy Hawking had previously published two unsuccessful comedy novels: Lucy Hawking, *Jaded* (London: Headline Review, 2003); Lucy Hawking, *The Accidental Marathon* (London: Headline Review, 2006).

⁶² However, it is notable especially in the light of ‘the Hawking effect’ discussed in Chapter 2 that Eric is not disabled.

⁶³ COSMOS, the UK National Cosmology Supercomputer, is a real supercomputer used at Cambridge. Stephen Hawking is a primary investigator on this project. ‘COSMOS Supercomputer’, accessed 17 May

the storyline of each book contains many references to specific scientific concepts, which are explained in separate informative sections. Keeping this information in separate sections has a twofold effect. First of all, it makes reader interaction self-paced and optional: the reader can choose not to interrupt the exciting adventure to read about scientific facts, but can come back to it later. Secondly, as these sections are shaded in grey textboxes, a reader wishing to look up facts later on can easily access these sections. From *Cosmic Treasure Hunt* onwards, the chapters about Annie and George alternate with short chapters, again on a grey background, in which Stephen Hawking and other well-known scientists explain the 'Latest Scientific Theories!' at essay length.

The narrative of each book is based on the rocketship adventure stories of the mid-twentieth century: in many of the 'juveniles' by Robert Heinlein (*Rocket Ship Galileo*) and Isaac Asimov (the Lucky Starr series, under the pseudonym of Paul French), children and teenagers explore the universe aided by skilful adult engineers.⁶⁴ The Hawkings supplement these tropes with other elements from contemporary young adult fiction, especially in *Blue Moon*, which contains a *Battle Royale*-like plot.⁶⁵ An important difference between the *George* books and the works by Stannard and Fong is that the main characters do not change in size, even when exploring galaxies one day

2017, <http://www.cosmos.damtp.cam.ac.uk/>. In the next *George* book, it is revealed that the fictional Cosmos is a quantum computer. Hawking and Hawking, *George's Cosmic Treasure Hunt*, 117.

⁶⁴ Robert A. Heinlein, *Rocket Ship Galileo* (New York: Scribner, 1947); Paul French, *David Starr, Space Ranger* (1952; repr., Kingswood: The World's Work, 1953).

⁶⁵ The Japanese novel *Battle Royale* (1999) and its film adaptation (2000) portray a dystopian world in which children and teenagers have to fight each other to death as mass entertainment; only the winner survives. This plot has become an immensely popular trope; the famous young adult (YA) novel *The Hunger Games* (2008) has an almost identical plot. In *Blue Moon*, no children die, but they do have to compete against each other, having been told that only the winning pair gets to go to Mars – and George and Annie are not paired together. Koushun Takami, *Battle Royale*, trans. Yuji Oniki (1999; repr., San Francisco: VIZ Media, 2006); Suzanne Collins, *The Hunger Games* (New York: Scholastic Press, 2008).

and quantum physics the next: Cosmos can make his users travel in space, but not in scale, or in time.⁶⁶

In a BBC interview given before the publication of *Secret Key*, Lucy Hawking claimed that it 'would be aimed at people like her own eight-year-old son.'⁶⁷ Both the publisher and reviewers, however, take age 8 as the minimum, describing this book as being suitable for children age 8-12.⁶⁸ Science popularizer John Gribbin gives one possible explanation for the discrepancy in target ages in his review: the content of the stand-alone informative boxes is 'pitched at a distinctly higher level of readership than the story itself'.⁶⁹ Notably, although George and Annie age over the course of the series, the books continue to be sold as suitable for children aged 8-12, as the marketing of *George and the Blue Moon* shows.⁷⁰ The books therefore seem to be addressing several different audiences: the storyline is aimed at younger children; the informational sections and the later books as George and Annie grow up are addressed to older children; the accessible manner in which cutting-edge science is communicated allows parents to discuss the latest science with their children.

⁶⁶ Alice Bell does claim that the first George book is an example of a children's science book that 'might shrink a character so they are small enough, like Buckley's fairies, to explore worlds the human eye cannot normally see', but this does not actually happen in any of the George books. Bell, 'Science as Pantomime', 61.

⁶⁷ 'Hawking to Write Children's Book', *BBC*, 13 June 2006, sec. Entertainment, <http://news.bbc.co.uk/1/hi/entertainment/5075516.stm>.

⁶⁸ 'George's Secret Key to the Universe', Simon & Schuster, 2016, <http://www.simonandschuster.com/books/Georges-Secret-Key-to-the-Universe/Stephen-Hawking/Georges-Secret-Key/9781416985846>; 'George's Secret Key to the Universe: Kirkus Review', Kirkus Reviews, 10 January 2007, <https://www.kirkusreviews.com/book-reviews/lucy-hawking/georges-secret-key-to-the-universe/#review>; Matt Berman, 'George's Secret Key to the Universe - Book Review', Common Sense Media, 17 December 2007, <https://www.common Sense Media.org/book-reviews/georges-secret-key-to-the-universe>.

⁶⁹ John Gribbin, 'George's Secret Key to the Universe, by Lucy and Stephen Hawking', *The Independent*, 16 October 2007, sec. Books, <http://www.independent.co.uk/arts-entertainment/books/reviews/georges-secret-key-to-the-universe-by-lucy-and-stephen-hawking-394921.html>.

⁷⁰ 'NEW Books for 8 to 12 Year Olds in March', World Book Day, 24 February 2016, <http://www.worldbookday.com/2016/02/new-books-for-8-to-12-year-olds-in-march/>.

The *George* series is rather conservative – the sort of book a parent would be happy to give to a child, rather than one a child might be eager to seek out on their own. One review, apparently aimed at parents who have encountered the *Horrible Science* series and would like to present their children with something less irreverent (and safer for their kitchen), reassuringly notes that ‘Parents need to know that there’s nothing objectionable here, and much to learn.’⁷¹ The roles of the parent characters are essential: in *Blue Moon*, a brief cyberbullying incident is resolved in a phone call between Annie’s parents and the mother of her bully.⁷² Conservatism in children’s (science) fiction is not uncommon, and has been a recurrent issue long before the Hawkings wrote their series. As Perry Nodelman points out, ‘fiction for young readers almost always offers both what adults think youngsters enjoy and what we think they need to know.’⁷³ Since adults, rather than children, will be the ones who purchase the *George* books, addressing adults’ expectations first is financially expedient. Science popularization for children emphasizes ‘what we think they need to know’, displaying a stronger adherence than adult popularizations to the old PUS model of science communication. The Hawkings’ series thus displays conservatism in both fiction and science communication.

The science in the *George* series, on the other hand, is cutting-edge. The series is notable for the inclusion of Stephen Hawking’s own research: as the front cover of *Secret Key* announces, the book ‘Includes the LATEST IDEAS about BLACK HOLES!’⁷⁴

⁷¹ Berman, ‘George’s Secret Key to the Universe - Book Review’.

⁷² Hawking and Hawking, *George and the Blue Moon*, 42–46.

⁷³ Perry Nodelman, ‘Out There in Children’s Science Fiction: Forward into the Past (Là-Bas, La Science Fiction Pour Enfants: En Avant Dans Le Passé)’, *Science Fiction Studies* 12, no. 3 (November 1985): 285–96, p. 292.

⁷⁴ Hawking and Hawking, *George’s Secret Key to the Universe*, front cover.

These ideas are part of the storyline, and are explicitly connected to contemporary scientific research in the grey-shaded boxes and chapters on the 'Latest Scientific Theories!'⁷⁵ With the grey chapters, a second audience might have been intended: parents or older readers familiar with these scientists can easily access these chapters without having to read the entire children's adventure story. In *Cosmic Treasure Hunt*, Stephen Hawking's essays are written under the name Eric; only the table of contents gives the names of both the real and the fictional scientist. Stephen and Eric are conflated to the point where science and fiction are no longer distinguishable, although Gribbin notes that 'It's hard to know what role Stephen actually played in the book's writing, as it credits Dr Christophe Galfard, one of his former students, with collaborating on "the scientific storyline, details and images".'⁷⁶ The use of Stephen Hawking as an author name seems to be functioning as a kind of branding, rather than as a reflection of authorial contribution. His author name as a brand helps sell the books, to shops in the first place, and to individual buyers second.⁷⁷ To those buyers, his reputation as a scientist functions as a guarantee of the authenticity and the accuracy of the science. Just as large numbers of adults have bought *A Brief History of Time* for its prestige and affective associations without necessarily having read it, such adults are now able to buy a book with the same associations for their child.

Whereas Stephen Hawking and Eric Bellis are conflated into the same persona in the first instalment, the two are separated again in later works. In *George and the Big*

⁷⁵ Hawking and Hawking, *George's Cosmic Treasure Hunt*, table of contents.

⁷⁶ Gribbin, 'George's Secret Key to the Universe, by Lucy and Stephen Hawking'.

⁷⁷ Juliet Gardiner, "What Is an Author?" Contemporary Publishing Discourse and the Author Figure', *Publishing Research Quarterly* 16, no. 1 (1 March 2000): 63-76, <https://doi.org/10.1007/s12109-000-1014-4>.

Bang, Hawking's essay is signed 'Dr Stephen Hawking', and in *George and the Unbreakable Code*, it is signed 'Professor Stephen Hawking'.⁷⁸ Both the scientific content of the series and the position of Eric as a character drift away from Stephen Hawking. The sequels cover scientific content outside Hawking's field, such as particle physics, computer science, and aerospace engineering. Eric as a scientist slowly changes fields to accommodate this content, making it difficult to continue to uphold parallels between Stephen Hawking and Eric. In *Secret Key*, Eric travels to Houston to launch a Mars lander; in *Big Bang*, he works for the Large Hadron Collider in Geneva; and in *Blue Moon*, he researches the practicalities of interplanetary travel. These areas no longer overlap with Stephen Hawking's own research. Eric travels back and forth between his work in Houston, Geneva, and the university of 'Foxbridge', allowing George and Annie to have exciting adventures abroad; in *Blue Moon*, when George and Annie have no means to travel, Eric works at Kosmodrome 2, an 'international space facility' close to Foxbridge.⁷⁹ He increasingly becomes a generic scientist, with his more specific job description adapted to the didactic purpose of each volume. The continuous adaptation of the research area of the scientist parent is also seen in Madeleine L'Engle's Murry family, discussed in the next chapter, in which the research field of the parents changes depending on what knowledge is necessary to enable the children's adventures in each novel. Sequelization has long been used as a common marketing technique in children's fiction and popular science, as Marcet's *Conversations* show, but the repeated use of the

⁷⁸ Hawking and Hawking, *George and the Big Bang*, table of contents; Hawking and Hawking, *George and the Unbreakable Code*, table of contents. The use of 'Dr' in 2011 but 'Professor' in 2014 is particularly odd, considering he was the Lucasian Professor of Mathematics from 1979 to 2009.

⁷⁹ Hawking and Hawking, *George and the Blue Moon*, 25. Kosmodrome 2 is presented as a new version of the real-world Cosmodrome in the desert of Kazakhstan. The child readers are clearly not expected to ponder the practicalities of launching a rocket next to a city.

same familiar authority figure leads to complications for science books. Works that show the same scientist character being an expert in rocket engineering and astrophysics (Eric Bellis) or even in microbiology and quantum physics (Mrs Murry) because authors wish to explore different topics in sequels overlook the nuances of specialization within scientific disciplines, perpetuating the mistaken idea that a scientist can make authoritative pronouncements on all sciences.⁸⁰

The scientist author, as well as the fictional scientist character, can come to stand for an authority in 'science' in a much wider sense due to popularizing efforts: popularizations are not necessarily written to communicate the author's own scientific work. There are several historical precedents: as Greg Myers points out, in the nineteenth century John Tyndall 'did important work on radiant heat, but he did not use his very popular works to promote his own discoveries: it was scientific education he saw himself as promoting.'⁸¹ In works for children, such an approach is even more common, since children would not necessarily be able to understand the specialist work most individual scientists undertake, and children's science books often cover a broader, more general topic than those for adults. Hawking, however, introduces some of his most important findings in the very first book in the *George* series: the structure of black holes, and Hawking radiation.⁸²

⁸⁰ Nevertheless, Stephen Hawking has not escaped this broadening out of his expertise in the public eye: his opinions have frequently been cited as expert views in fields outside his own, such as artificial intelligence and climate change. Rory Cellan-Jones, 'Stephen Hawking Warns Artificial Intelligence Could End Mankind', *BBC News*, 2 December 2014, sec. Technology, <http://www.bbc.co.uk/news/technology-30290540>; 'Stephen Hawking at 75: Trump and Climate Change', *BBC News*, accessed 9 September 2017, <http://www.bbc.co.uk/news/av/science-environment-40473841/stephen-hawking-at-75-trump-and-climate-change>.

⁸¹ Greg Myers, 'Nineteenth-Century Popularizations of Thermodynamics and the Rhetoric of Social Prophecy', *Victorian Studies* 29, no. 1 (1985): 42.

⁸² In *Big Bang*, Hawking's research is again referred to, in the 'Latest Scientific Theories!' essay by Kip Thorne, who writes that 'Remarkably, Stephen has proved (using the laws of physics) that every time

In *Secret Key*, Hawking radiation is explained, a quantum mechanical phenomenon that is usually not taught below university level. Rather than anthropomorphizing abstract phenomena, as Stannard and Gilmore have done, the Hawkings make use of a technological intervention. Cosmos is able to reproduce the phenomenon in the living room. When Eric is about to be swallowed by a black hole, he tells George to look for his book on black holes to find a way to save him. George looks through Eric's books, which are existing scientific monographs, and doesn't understand a word of them: *Euclidean Quantum Gravity* and *Unified String Theories*, which are both existing scientific monographs, and *Black Holes*, 'a very difficult textbook for professional researchers' that is supposed to contain the solution to Eric's predicament.⁸³ Within this book Eric has hidden a simplified summary for George and Annie, which explains Hawking radiation: the next chapter is this 'summary', which ends with the message, 'So the memory of what falls into a black hole is not lost forever, just for a very long time. YOU CAN GET OUT OF A BLACK HOLE!'⁸⁴ Realising that Hawking radiation is the key to saving Eric, George is able to instruct Cosmos to reassemble Eric as his individual particles are radiated out again. Eric emerges again from the computer, all his memories intact; the only error Cosmos made is that Eric is now wearing the wrong glasses.⁸⁵

machine requires negative energy, so this would prevent *any* time machine from being made.' Hawking and Hawking, *George and the Big Bang*, 252.

⁸³ G. W. Gibbons and Stephen Hawking, eds., *Euclidean Quantum Gravity* (Singapore: World Scientific, 1993); Michael B. Green and David Gross, eds., *Workshop on Unified String Theories: 29 July-16 August 1985, Institute for Theoretical Physics, University of California, Santa Barbara* (Singapore: World Scientific, 1986); Hawking and Hawking, *George's Secret Key to the Universe*, 229.

⁸⁴ Hawking and Hawking, *George's Secret Key to the Universe*, 239.

⁸⁵ The glasses come up again in *George and the Big Bang*, in which it is revealed that they used to belong to the mad scientist Professor Zuzubin, Eric's former supervisor, who turned evil when the world forgot him after young Eric overthrew his theory.

This approach to the black hole information-loss paradox involves the George books in the conflict covered in Chapter 2. Although the paradox is never named in *Secret Key*, the narrative assumes Susskind's interpretation of the paradox: information is *not* irretrievably lost in a black hole. In this book, Hawking agrees with Susskind on information loss. *Secret Key* was Hawking's first popular work since publicly admitting, at a conference in 2004, that information does leak out of black holes.⁸⁶ Susskind closes *The Black Hole War* with this admission, to show that Hawking finally considered Susskind's long-held view to be correct. In fact, as Susskind points out, Hawking did not officially concede to having lost bets with John Preskill and Don Page on this topic until 2007,⁸⁷ the same year in which the first *George* book was published.

The Hawkings do, however, express a continued opposition to string theory. *Cosmic Treasure Hunt* introduces a pedantic genius boy called Emmett, who suggests that the information-loss paradox is not entirely resolved yet: he does not want to go to the beach because 'I've got my theories on the information-loss paradox to work on.'⁸⁸ Annie in particular strongly dislikes this boy who curses with the phrase 'Holy supersymmetric strings!'.⁸⁹ Eric is visibly uncomfortable when Emmett finds an error in 'Eric's' *The Large-Scale Structure of Spacetime*, another existing monograph, by Hawking and George Ellis.⁹⁰ He tells Emmett, 'No one's ever spotted that before but that doesn't mean you're wrong.'⁹¹ Eric suggests that there might be a very small

⁸⁶ Stephen Hawking, 'Black Holes and the Information Paradox', in *Proceedings of the 17th International Conference, RDS Convention Centre, Dublin, 18-23 July 2004* (General Relativity and Gravitation, World Scientific, 2005), 56–62, https://doi.org/10.1142/9789812701688_0006.

⁸⁷ Susskind, *The Black Hole War*, 444.

⁸⁸ Hawking and Hawking, *George's Cosmic Treasure Hunt*, 105.

⁸⁹ Hawking and Hawking, 117.

⁹⁰ S. W. Hawking and G. F. R. Ellis, *The Large Scale Structure of Space-Time* (1973; repr., Cambridge: Cambridge University Press, 2008).

⁹¹ Hawking and Hawking, *George's Cosmic Treasure Hunt*, 125.

chance that his science is flawed, but that an apparently large number of scientists have read his work before and agree with him. However, he doesn't want to admit that Emmett might be correct: when the boy is about to suggest a way to rectify it, Eric quickly changes the subject to going out for an ice cream.⁹² The Hawkings make Emmett stand for a string theorist: someone they respect as a genius academic, but whom they do not necessarily like, whose theories most scientists do not support, and whose ideas they don't want to explore further. The children's books are thus reflecting the state of cutting-edge scientific disputes even if the disputes themselves are not taken up in these texts.

Quantum physics is one of many scientific fields addressed in the *George* books; the third and fourth book, *Big Bang* and *Unbreakable Code*, contain most of the quantum physics exposition. The format of the books limits the extent to which the field can be explained to child readers: in *Big Bang*, one grey information page is dedicated to the difference between classical and quantum physics, and one page explains Schrödinger's cat paradox.⁹³ No space is dedicated to the co-existence of various interpretations of quantum physics; however, from the narrative and the discussion of Schrödinger's cat, one can deduce that the books adhere to the Copenhagen interpretation. In such a limited space, the Hawkings have not reserved any room for either naming the interpretation they are using as the Copenhagen interpretation or explaining that various interpretations exist simultaneously; Stephen Hawking similarly omitted the existence of multiple interpretations from *A Brief History of Time*. The resolution of the plot of *Big Bang*, which combines quantum physics with particle physics, proves that

⁹² Hawking and Hawking, 126.

⁹³ Hawking and Hawking, *George and the Big Bang*, 239–40.

scientific uncertainty itself is not the reason why an explanation of the co-existing interpretations is avoided. The formerly evil scientist Dr Reeper has invented a 'quantum mechanical bomb' that is about to blow up the Large Hadron Collider:

'The bomb has been armed in such a way that no one switch can turn it off; it is in a quantum superposition of eight different possible switches. The detonator does not "decide" which switch is actually being used until someone presses one to try and stop the bomb going off, and the circuit checks whether it is correct. At that point the wave function collapses randomly to one of the eight possible alternatives. Even if you pressed all eight at once, the bomb will very probably detonate immediately.'⁹⁴

The collapse of the wave function by means of pressing a switch implies that the Copenhagen interpretation must be adhered to. It is not clear how either George or the reader is supposed to understand Reeper's explanation; the grey box explanation follows eighty pages after this exposition. George somehow understands the concept of superposition, however: when the evil scientist Professor Zuzubin locks them in an 'Inverse Schrödinger Trap' in which they do not know where in the universe they are until they observe what's outside the trap, he is able to explain to Annie that they are safe, but that they could die when they open the door.⁹⁵ They are saved when Annie's friend Vincent is able to collapse their location onto the Large Hadron Collider.

From here on, quantum physics is abandoned in favour of particle physics. George understands that he must disarm the bomb, which is hidden in the LHC in the guise of a drinks machine with eight buttons that each produce a particle-themed drink. George needs to press the right switch to disarm the bomb, and realises that one of the

⁹⁴ Hawking and Hawking, 162. Dr Reeper is a recurring character: in the first two books he was an evil scientist, but he has been made to come to his senses and has now infiltrated an organization led by a real evil scientist, Professor Zuzubin. This organization has asked Reeper to build a bomb to blow up all the physicists in the world; unfortunately, Reeper's ego made him unable to sabotage his own creation: 'How could I make something that didn't work!' Hawking and Hawking, 160.

⁹⁵ Hawking and Hawking, *George and the Big Bang*, 233.

particles is unlike all the others: “Higgs,” said George quickly. “It’s the *theoretical* one. All the rest – we know about them, we know they exist. But we don’t know if the Higgs particle really exists or whether it’s just a useful way of making the rest of our knowledge fit together nicely.”⁹⁶ The existence of the Higgs boson was confirmed in 2012, a year after the publication of this book.⁹⁷ The Hawkings were willing to include science so cutting-edge that its ontological status was to change a year later.

The Higgs drink is introduced in order to teach the reader about the Higgs boson, but the quantum physics has been side-lined: the distinguishing feature of the bomb was that it is impossible to know in advance which of the switches could turn it off. George explains that he was able to switch off the bomb because Dr Reeper had somehow ‘in secret already made an observation.’⁹⁸ The rushed coverage of quantum theory makes it impossible for a reader to question its status or to realise it is not fully understood yet by the scientific community, especially when it is presented alongside a narrative which hinges on the Higgs boson being hypothetical. The presentation of quantum physics confirms Gribbin’s claim in his review of the first *George* book that the content of the informational boxes is pitched at a much higher level than the narrative. The reader who is able to understand the explanation at all will learn that it is established scientific knowledge that the wavefunction collapses under observation. In the *George* books the Hawkings only discuss resolved conflicts such as the black hole information-loss paradox, in order to present physics as a unified and ever-improving effort to find out more about the universe. Those who get stuck in past conflicts are

⁹⁶ Hawking and Hawking, 268.

⁹⁷ G. Aad et al., ‘Observation of a New Particle in the Search for the Standard Model Higgs Boson with the ATLAS Detector at the LHC’, *Physics Letters B* 716, no. 1 (17 September 2012): 1–29, <https://doi.org/10.1016/j.physletb.2012.08.020>.

⁹⁸ Hawking and Hawking, *George and the Big Bang*, 272.

evil: all the good physicists in the world work together on the Higgs boson, and those who oppose this work, afraid that their theories might be overthrown, are terrorists who must be stopped. The scientific establishment is presented as unequivocally progressive in order to encourage young readers to join the establishment later on.

The Quantum Bunny

Otto Fong's *The Quantum Bunny* (2015) is the fifth instalment in the graphic novel series *Sir Fong's Adventures in Science* (2008-present). Fong wrote this book when he was an Outreach Fellow at the Centre of Quantum Technologies (CQT) of the National University of Singapore. He is not trained as a physicist: he was an engineer, then a school-teacher, then an artist. He had the concepts of quantum physics explained to him by CQT scientists and graduate students, who appear as characters in the comic.⁹⁹ The book incorporates quantum physics in a reworking of the first chapters of the sixteenth-century Chinese novel *The Journey to the West*,¹⁰⁰ which is considered one of China's four great classical novels: just as Stannard uses an Alice in Wonderland setting with which British children will in one way or another be familiar, Fong uses a story his Singaporean audience will have grown up with.

The first fifteen chapters of the 100-chapter *The Journey to the West* describe how the Monkey King rebelled against Heaven and was imprisoned under a mountain by the Buddha; in this comic the Quantum Bunny, called Qubit, rebels against the palace

⁹⁹ 'Bunny Takes On Quantum Physics', NUS News, 16 November 2015, <http://news.nus.edu.sg/highlights/bunny-takes-quantum-physics>.

¹⁰⁰ Cheng'en Wu, *The Journey to the West*, trans. Anthony C. Yu (1592; repr., Chicago: University of Chicago Press, 1977).

of the Sky Emperor, Albert Einstein. The bunny breaks into the palace through quantum tunnelling, but is eventually trapped under the mountain in a hadron collider. The story is thus an allegory for the way in which quantum physics overthrew classical physics in the early twentieth century. Just like *Uncle Albert and the Quantum Quest*, *The Quantum Bunny* shows the conflict inherent in quantum physics at the time of its inception; in both works, Einstein's famous 'God does not play dice' quotation is repeated as Einstein is shown to reject the uncertainty principle.¹⁰¹ Fong, too, only covers the development of quantum physics during Einstein's lifetime, and does not mention the conscious collapse and many-worlds interpretations or their inventors.

Notably, this book does not attempt to explain quantum physics the way the previously mentioned works do: it is rather a fictionalized narration of the historical development of the field. A newspaper reports that Fong 'stressed that it will not teach quantum physics to young people but will make some of its concepts familiar to them.'¹⁰² At the end of the book, a list is given of topics that have been displayed in the book, so that the reader can look them up and learn more about them. As this is a comic, Fong has chosen not to break up the narrative with explanatory sections as the Hawkings have done, and instead presents an immersive story that does not distract the reader with information boxes or assignments: entertainment is the main purpose of the book. Fong aims to familiarize his readers with quantum physics concepts from a young age onwards and to make their first encounter with the concepts a memorable experience:

What we can do is introduce the concepts as enjoyable, memorable entertainment. When the children grow older and have the capacity to grasp quantum

¹⁰¹ Stannard, *Uncle Albert and the Quantum Quest*, 118; Fong, *The Quantum Bunny*, 145.

¹⁰² Shaffiq Alkhatib, 'Quantum Physics for Kids', *The New Paper*, 31 October 2015, 20.

mechanics, they will find the concepts welcoming, familiar as part of their childhood, and embrace rather than reject them.¹⁰³

Although the publication of *The Quantum Bunny* was covered in the media, the book has so far not been reviewed, so it is unclear whether other educators and physicists agree that this approach is successful. However, familiarization with scientific concepts at an early age has been implemented before in successful children's book series: the next chapter will discuss two authors who followed this approach, although not in a humorous way.

Experiments

Science popularizations have been linked to experimentation for centuries, and have created financially successful franchises: a brief overview can be found in Bell's thesis.¹⁰⁴ Using *Horrible Science* as a case study, in earlier research I have argued that including experiments in science books for children enhances the readers' engagement as they are able to feel in control. The *Horrible Science* series makes use of negative affective responses (horror, disgust) as well as positive ones (excitement) to engage children.¹⁰⁵ As the experiments are always optional, they can provide an opportunity for controlling the intensity of affective engagement: unlike in school science, children can choose whether or not to perform the experiments many science books suggest.

Further options for experiments can be added even after the publication of the books, through branded experiment kits. The Tom Telescope book provided a very

¹⁰³ 'Otto Fong: Outreach Fellow, 2014–15', Centre for Quantum Technologies, accessed 11 July 2016, https://www.quantumlah.org/outreach/projects/otto_fong.php.

¹⁰⁴ Bell, 'Science as Pantomime', 62–63.

¹⁰⁵ Kanta Dihal, 'Amazing Affects: The Evocation of Affects in Science Popularizations for Children' (Leiden University, 2014), <https://openaccess.leidenuniv.nl/handle/1887/28665>.

early form of product tie-ins, which can still be seen in science popularizations to this day. At the back of the work, the publisher included ‘A List of the Optical and Philosophical Instruments mentioned in this Book; with the Prices at which they are made and sold, by the Philosophical Instrument Makers. [...] Orders sent to the Publishers of this Work, will be duly attended to.’¹⁰⁶ In the twenty-first century, children can buy science sets that are made to tie in with specific popular science books: there are science kits available to accompany several *Horrible Science* books, for instance, such as ‘Explosive Experiments: The Kit’, and ‘Space, Stars and Slimy Aliens: The Kit’. Most modern science experiments for children are based on nineteenth-century and earlier experiments, as these could be performed at home: the *Horrible Science* experiments include testing Galileo’s theories regarding falling bodies,¹⁰⁷ and preventing an apple from rotting by sprinkling it with lemon juice.¹⁰⁸ The series also offers some tangible experiments that children could perform to improve their understanding of modern physics: blowing up a balloon with dots on it to simulate the expansion of the universe, for instance.

However, there are no quantum physics experiments which can be performed by a young reader alone: most experiments require specialist equipment, and even the cheapest experiments are not completely child-friendly. Performing the double-slit experiment, for instance, requires the use of a laser pointer. The hands-on element of science is normally vital to science books for children; the books under discussion here need to replace this element as they address science that is too abstract to work with

¹⁰⁶ Telescope, *The Newtonian System of Philosophy*, 139.

¹⁰⁷ Nick Arnold, *Suffering Scientists*, *Horrible Science* (London: Scholastic, 2000), 75–76.

¹⁰⁸ Nick Arnold, *Chemical Chaos*, *Horrible Science* (London: Hippo, 1997), 114–15.

manually. Therefore, the fictional component of the stories becomes more important as the practical execution becomes impossible. The authors of these books close off the world in which their books are set from our world, through a fictional component. There is then no option at all left for the reader to repeat any of the experiments or adventures covered in this book, as it is clear that the reader is not in the supernatural position in which the protagonists of the book find themselves. Experimentation, therefore, takes place entirely in the imaginative realm.

Barbara Wall argues that active audience participation is an essential element even in children's fiction such as that written by C.S. Lewis or Roald Dahl:

Many child readers respond favourably to the sense of security given to them by the familiar voice of the explaining, rather patronising, narrator, as the tone in such stories has much in common with the tone of a particular kind of oral story-teller, one who holds attention not so much by the quality of the story as by constantly demanding active audience response.¹⁰⁹

Active audience response can be provoked even when the reader is not instigated to action outside the book: Wall mentions directly addressing the narratee, and demanding a response from them, as the most important example.¹¹⁰ Russell Stannard in particular has solved this issue through referring to thought experiments, and centring his works around them rather than around practical experiments. In fact, he writes that the double-slit experiment would 'need the sort of source you get in a lab', after Gedanken has unsuccessfully tried to create light diffraction using sunlight and her hands.¹¹¹ His book does have an interactive element, which nevertheless is theoretical: the story ends with a quiz, which Gedanken has ostensibly created for her uncle to

¹⁰⁹ Barbara Wall, *The Narrator's Voice: The Dilemma of Children's Fiction* (Houndmills: Macmillan, 1991), 18.

¹¹⁰ Wall, 17.

¹¹¹ Stannard, *Uncle Albert and the Quantum Quest*, 41.

make clear to him how educational computers can be. The answers are included at the end of the quiz.¹¹² By focusing entirely on thought experiments, he makes clear to the reader how important they are in the development of modern theories of physics; however, this leaves him with very little opportunity to discuss the ways in which the outcomes of thought experiments are verified. Since Gedanken is able to physically experience a thought experiment, experimental verification of theories developed by means of thought experiments has no room in Stannard's series. Such verification is central to modern physics, as the example of the Higgs boson above showed: the existence of the particle was first theorized in the 1960s, but it was treated as hypothetical until experimental verification confirmed the theory in 2012.¹¹³

Comparison to the Classroom

Several authors have argued that popularizations can supplement what is taught in class.¹¹⁴ As Alice Bell points out, several 'domestic non-fiction' books contain explicit references to specific parts of national curricula to which their content corresponds.¹¹⁵ Although the classroom can normally provide the opportunity to visualize and perform more advanced experiments, most quantum physics experiments would still be beyond the reach of most schools – and the topic of quantum physics is currently not part of

¹¹² Stannard, 131–40.

¹¹³ Peter W. Higgs, 'Broken Symmetries and the Masses of Gauge Bosons', *Physical Review Letters* 13, no. 16 (19 October 1964): 508–9, <https://doi.org/10.1103/PhysRevLett.13.508>.

¹¹⁴ Ogborn et al., *Explaining Science in the Classroom*; Jonathan Osborne and Justin Dillon, eds., *Good Practice in Science Teaching: What Research Has to Say*, 2000. 2nd ed. (Maidenhead: Open University Press, 2010).

¹¹⁵ Bell, 'Science as Pantomime', 57.

the school curriculum for 8-13-year-old students, although it is taught increasingly often to pre-university students.¹¹⁶ In books about quantum physics, the child will therefore be taught something much further removed from their classroom teaching than most popularizations will address, often even before they will have heard of classical mechanics. The author therefore faces the problem of engaging children with books on a topic they have not in the least encountered in school yet. They have likely not heard of the topic before reading this book and now they have to grasp these concepts too complicated for everyone but the most advanced physicists to comprehend.

Convincing Children to Become a Scientist

Popular science for children is written with different intentions than those behind the works written for adults. Lightman shows that, since the nineteenth century, popular science for adults has tended to be exclusionary:

Though [T.H.] Huxley encouraged support and interest in science he nevertheless excluded amateurs from engaging in scientific work in the laboratory and field. It was during the latter half of the century that the term 'popular science' began to take on some of its pejorative connotations.¹¹⁷

Science books for children, however, cannot exclude the reader from the experts in this manner, because one cannot tell which child readers of these books will end up becoming experts. Bell points out that in the 'post-Sputnik era' many children's science books were written with the intention to recruit young scientists.¹¹⁸ This recruitment trend

¹¹⁶ K. Krijtenburg-Lewerissa et al., 'Insights into Teaching Quantum Mechanics in Secondary and Lower Undergraduate Education', *Physical Review Physics Education Research* 13, no. 010109 (17 February 2017), <https://doi.org/10.1103/PhysRevPhysEducRes.13.010109>.

¹¹⁷ Bernard Lightman, 'Preface to Popular Science in the Nineteenth Century', in *Evenings at Home, or The Juvenile Budget Opened I-III*, by John Aikin and Anna Laetitia Barbauld (Bristol: Thoemmes Press, 2003), v-ix, p. vii.

¹¹⁸ Bell, 'Science as Pantomime', 62.

can still be seen in the works under discussion here: Stannard ends his book with the message, 'Perhaps one day someone will come along and solve the riddle of the quantum once and for all. Who knows, that long-awaited scientist might even turn out to be – YOU!'¹¹⁹

Children's books can afford to make a lack of definitive answers sound exciting. The author can utilize the claim that certain factors are as yet unknown in order to make the profession of the physicist more appealing to the child: as the child grows up, they might become the scientist who makes this ground-breaking discovery. The children in the popularizations discussed in this chapter are already able to make such discoveries. Gedanken, George, and Annie make important contributions to science through their involvement in the stories in ways that the adults cannot. Uncle Albert needs Gedanken's help when he is stuck, and is sad at the start of the book because he thinks Gedanken is no longer willing to travel into his thought bubbles after her spaceship crashed into a black hole in the last adventure.¹²⁰ The children's curiosity, as well as their ability and willingness to travel and explore, is immediately rewarded, as they work together with scientists who can provide them with the right amounts of knowledge when they need it. As Bell explains, 'Gedanken's questions and youthful imagination drive the books' narrative, but she always works within her uncle's authority and experiential knowledge. Albert points out how other people have already answered her questions and frames her exploration'.¹²¹ The child protagonists learn to value their own work, while they are still children, but their contributions are always

¹¹⁹ Stannard, *Uncle Albert and the Quantum Quest*, 143.

¹²⁰ Stannard, 3–4.

¹²¹ Bell, 'Science as Pantomime', 24.

made to count within the official scientific framework. In this imagined scenario, the children and adults require each other equally.

Over the course of the *George* series, Annie and George grow up along with their initial readership, slowly growing and being encouraged into the official scientific establishment: in *George and the Big Bang*, George and Annie attend secondary school for the first time and Annie becomes interested in a boy other than George. In *George and the Blue Moon*, the two are hired as ‘junior astronauts’ through a programme that ostensibly will prepare them for a Mars mission to be undertaken when they reach adulthood. The fact that they choose this official training within the scientific establishment when they have Cosmos who can send them around the universe is explained by new regulations that Cosmos has to comply with: he is no longer allowed to send children out into space. Of course, they do end up going there, when the junior astronaut programme turns out to be Eric’s nemesis’s smokescreen for an expedition on Europa that will bring an army of robots to life. The narrative constantly negotiates a balance between the non-scientific adventure story and the engagement with real science, emphasizing that although Annie and George are allowed to do and see more, they find real science exciting enough to want to become part of the scientific establishment.

Conclusion

Children’s popularizations of quantum physics lack the opportunity of engaging the child through means other than reading, as physical experiments in quantum physics are not available to children. The works discussed in this chapter replace this lack by providing a fictional adventure story, comparable to the scientific fantasies for adults discussed in the previous chapter. The works rely on analogies with existing stories,

with Lewis Carroll's *Alice's Adventures in Wonderland* being often relied on by popularizers for adults and children alike. As the provider of stock metaphors and analogies, or even the entire storyline, the story is known for its engagement with the impossible and seemingly nonsensical. Lucy and Stephen Hawking's *George* books, on the other hand, fit into a long-standing tradition of rocketship adventure stories that hark back to the golden age of science fiction. Otto Fong has a more exploratory and less didactic intention in *The Quantum Bunny*, but presents his narrative that involves hadron colliders and quantum computing in the context of an even older, sixteenth-century novel. The authors facilitate engagement by means of an existing narrative that has already proven to be engaging.

Not all science books for children make use of a scientifically fantastic story; the works in this chapter show that this genre is most suitable for making a single complicated scientific topic understandable to children. Whereas other science books, such as the *Horrible Science* series, are based on conveying a series of small facts and tidbits of knowledge around a general area, the works in this chapter use a coherent narrative to slowly build up understanding of a topic that is often presented as incommunicable to adult non-experts. The reader is meant to carry forward the concepts and ideas encountered throughout the book; experiments, which would let the reader step away from the book, are not included – quantum physics experiments for children do not exist, but are also undesirable in this context. Theory is more important than experimentation in these works: this approach allows authors to make use of imaginative fictional constructions. The use of this form implies, however, that the role of experimentation is largely left out of the narrative, which means that the reader will not learn about the verification of the theories to which they have just been introduced.

Even though the works discussed engage with a cutting-edge scientific topic, the scientific fantasy form pushes authors toward conservatism and nostalgia. Harking back to centuries-old narratives, the authors make use of the works that shaped their own childhoods. *Stannard* and *the Hawkings* require their child protagonists to validate their adventures and observations with adult, usually male, scientist characters, by means of the old-fashioned dialogue form. Even as the authors show an awareness of a changed cultural context, whether that happens by means of intradiegetic questioning of the source narrative, by using contemporary slang, by referring to computers, or by using modern drawing styles, they make this modern approach dependent on a narrative older than quantum physics.

Embedded in these nostalgic tales, however, the child reader will discover conflict narratives that show that disagreements in science are common. Even though the children's books do not dedicate any space to the various interpretations of quantum physics, they tell tales of scientists who resist new developments and hold on to established theories. These children's books, then, construct an idea of science as contested and in constant flux from a very young age onwards, shaping the way science is perceived in the scientists of tomorrow.

Chapter Five: Quantum Mechanics and Religion in Madeleine L'Engle's *Time Quintet* and Philip Pullman's *His Dark Materials*

Introduction

Science fiction for children, paradoxically, often takes up an explicitly anti-scientific and/or anti-technological viewpoint. As Noga Applebaum argues, 'contemporary Young SF [...] frequently demonises technology as the cause of a range of ailments [...] the solution to the problem is a disengagement from or rejection of technology rather than utilisation of it for the greater good.'¹ In the early twentieth century, Jessica Yates claims, authors such as Rudyard Kipling, who occasionally wrote science fiction for adults, adhered to fantasy for their children's books because those did not need a scientific component. The fantasy is so easily accepted: 'Since children willingly accepted magic, there was no need for a pseudo-scientific explanation for supernatural events.'² According to Michael M. Levy, another reason why there are so few science fiction works for children is that 'it is difficult to convey scientific marvels to anyone who lacks an adequate grounding in basic science.'³ However, as the works in the previous chapter show, a grounding in more than basic science can be given to children aged 8 to 12. Farah Mendlesohn urges science fiction authors to 'offer a type of challenge which moves away from an assumption that literature for children should reinforce what they

¹ Noga Applebaum, *Representations of Technology in Science Fiction for Young People*, Ebook (New York: Routledge, 2010), Introduction.

² Jessica Yates, 'Science Fiction', in *International Companion Encyclopedia of Children's Literature*, ed. Peter Hunt, Second ed., vol. 1, 2 vols (London: Routledge, 2004), 519–31 p. 521.

³ Michael Levy, 'Editor's Introduction II: Boys and Science Fiction', *The Lion and the Unicorn* 28, no. 2 (2004): ix–x, <https://doi.org/10.1353/uni.2004.0021>.

already recognize.’⁴ The works I discuss in this chapter have indeed moved away from this assumption and make use of scientific concepts that are new to the child reader in order to construct fictional worlds.

In this chapter, I will present a close analysis of two famous children’s book series in which quantum physics is essential to the storyline: Madeleine L’Engle’s *A Wrinkle in Time* series, also known as the Time Quintet (1962-1989) and Philip Pullman’s *His Dark Materials* trilogy (1995-2005). Both series are usually categorized as fantasy; however, science, and science-based novae in the Suvinian sense, play an essential role in the plots of both. The science is used both to make the fantasy more believable and to reinforce the argument the author is making about religion. These series are radically different, yet their similarities with respect to science are striking: science is used to create a fantastical world, in which religion is central, and which is made more believable through its foundation in modern physics. However, whereas in Pullman’s works organized religion is explicitly attacked, L’Engle’s novels are strongly Christian, presenting a positive view of religion which transcends science, while making the claim that a similar approach in both science and religion is necessary. Both series introduce advanced scientific concepts that young readers will not encounter within an institutional context until they are close to adulthood. The science content has a fundamental impact both on the narrative structure of the texts and on the shape of the argument regarding religion.

Mendlesohn claims that one of the reasons why children’s science fiction has not developed as extensively as the adult branch is that the genre ‘seems to be limiting

⁴ Farah Mendlesohn, ‘Is There Any Such Thing as Children’s Science Fiction?: A Position Piece’, *The Lion and the Unicorn* 28, no. 2 (2004): 284–313, <https://doi.org/10.1353/uni.2004.0022>, p. 285.

itself in some cases through an insistence on didacticism'.⁵ Karín Lesnik-Oberstein, on the other hand, argues that children's literature is always consciously or unconsciously didactic.⁶ L'Engle and Pullman approach didacticism from different angles. Pullman does not explain the scientific concepts he mentions: the didacticism lies in the moral lessons he intends to convey, whereas the science concepts are hinted at to evoke curiosity in the reader and to support the primary argument about a democratic approach to knowledge. L'Engle's presentation of biblical ideas to her readers is explicitly didactic, and the setting that is part science fiction and part fantasy is meant to facilitate learning. L'Engle considered the reading of fantasy and science fiction during one's childhood important for being able to understand science at a later age: 'A child denied imaginative literature is likely to have more difficulty understanding cellular biology or post-Newtonian physics than the child whose imagination has been stretched by fantasy and science fiction.'⁷ She supported the idea that reading these genres would have an educational purpose.

Madeleine L'Engle: Science and Religion as Personal

US author Madeleine L'Engle (1918-2007) combined her Christian religion with her interest in science in a prolific writing career that mostly encompassed children's books. Her *A Wrinkle in Time* (1962) was the first instalment in what would grow into

⁵ Mendlesohn, 286.

⁶ Karín Lesnik-Oberstein, *Children's Literature* (Oxford: Oxford University Press, 1993), 37, <https://doi.org/10.1093/acprof:oso/9780198119982.001.0001>.

⁷ Madeleine L'Engle, 'Childlike Wonder and the Truths of Science Fiction', *Children's Literature* 10, no. 1 (1982): 102-10, <https://doi.org/10.1353/chl.0.0656>, p. 105; Stephen Winick, 'Einstein's Folklore', Library of Congress: Folklife Today, 18 December 2013, <http://blogs.loc.gov/folklife/2013/12/einsteins-folklore/>.

the series that is now usually known as the Time Quintet.⁸ Its sequels are *A Wind in the Door* (1973), *A Swiftly Tilting Planet* (1978), *Many Waters* (1986), and *An Acceptable Time* (1989).⁹ The protagonists of the books are the Murry family: the scientists Mr and Mrs Murry,¹⁰ their four children – Meg, the twins Sandy and Dennys, and the child prodigy Charles Wallace – and Meg’s boyfriend and later husband Calvin O’Keefe. In each book the children discover, through a connection with their parents’ research, that they need to save the world. Though the books have a chronological order (*Wrinkle – Wind – Waters – Planet – Acceptable*), there are hardly any references to earlier adventures in the later books. The balance between science and religion varies in each book: *Wrinkle* contains entire chapters of scientific exposition, even including diagrams, but scientific concepts are only mentioned on five pages in *Planet*. Similarly, whereas no direct mention is made of Christianity in *Wind*, *Waters* is a retelling of the story of Noah’s Ark, and in *Acceptable*, when a bishop discovers how to travel between different ‘time circles’, Mr Murry claims that ‘a theologian and not a scientist [has] made a discovery which it has taken me a lifetime to work out’.¹¹ As L’Engle brings together scientific and supernatural plot arguments, Brian Attebery argues that her works are an example of the ‘dissensus fantastic’: ‘fiction that places scientific materialism within a larger conceptual framework that includes the supernatural’.¹²

⁸ L’Engle, *A Wrinkle in Time*. Henceforth *Wrinkle*. Since the quintet was published over several decades, older criticism such as Patterson’s refers to the first three books as the ‘“Wind” Trilogy’; Hearne refers to it as the ‘Time Fantasy Series’. Nancy-Lou Patterson, ‘Angel and Psychopomp in Madeleine L’Engle’s “Wind” Trilogy’, *Children’s Literature in Education* 14, no. 4 (1983): 195–203, p. 202. Betsy Hearne, ‘A Mind in Motion’, *School Library Journal* 44, no. 6 (June 1998): 29.

⁹ L’Engle, *A Wind in the Door*. Henceforth *Wind*. L’Engle, *A Swiftly Tilting Planet*. Henceforth *Planet*. L’Engle, *Many Waters*. Henceforth *Waters*. L’Engle, *An Acceptable Time*. Henceforth *Acceptable*.

¹⁰ Neither scientist is referred to as Dr. or Professor anywhere in the series, unlike the medical doctor Louise Colubra, who is referred to as Dr. throughout.

¹¹ L’Engle, *An Acceptable Time*, 66.

¹² Attebery, ‘The Fantastic’, p. 131, 136.

In an undated interview appended to the 2007 Square Fish edition of *Wrinkle*, L'Engle stated that she got the idea for the novel when 'I started reading what Einstein wrote about time. And I used a lot of those principles to make a universe that was creative and yet believable.'¹³ Reading Einstein's work provided her with a theology she had been struggling to find:

Before I wrote *Wrinkle*, I picked up a book in which Einstein was quoted as saying, 'Anyone who is not lost in rapturous awe at the power and glory of the mind behind the universe is as good as a burnt-out candle.' And I thought, 'oh, I have found my theologian.'¹⁴

Her paraphrase significantly alters Einstein's original words, which do not contain a reference to a 'mind'. In fact, Einstein speaks out against a conscious mind. L'Engle has likely read the 1935 English translation by Alan Harris, which is still in print, or a work that quotes from it. It is Harris who introduces the candle analogy L'Engle quotes, which Einstein's original German text did not contain. Harris translates Einstein's 'seine Auge erloschen' (literally 'his eyes extinguished')¹⁵ as 'a snuffed-out candle':

The fairest thing we can experience is the mysterious. [...] He who knows it not and can no longer wonder, no longer feel amazement, is as good as dead, a snuffed-out candle. It was the experience of mystery – even if mixed with fear – that engendered religion. A knowledge of the existence of something we cannot penetrate, of the manifestations of the profoundest reason and the most radiant beauty, which are only accessible to our reason in their most elementary forms – it is this knowledge and this emotion that constitute the truly religious attitude; in this sense, and in this alone, I am a deeply religious man. I cannot conceive of a God who rewards and punishes his creatures, or has a will of the type of which we are conscious in ourselves.¹⁶

¹³ L'Engle, *A Wrinkle in Time*, 236.

¹⁴ Hearne, 'A Mind in Motion', 31.

¹⁵ Albert Einstein, *Mein Weltbild* (Amsterdam: Querido, 1934).

¹⁶ Albert Einstein, *The World as I See It*, trans. Alan Harris (1935; repr., London: The Bodley Head, 1941), 5.

If L'Engle indeed had direct access to this English translation, she actively altered Einstein's claim. Both in the original German and in this translation, Einstein explicitly rejects the idea of a conscious mind behind the universe; the sense of wonder he is talking about refers not to a creator, but to the concept of the mysterious. Rather than finding a theology in Einstein's words, L'Engle altered them to make a theologian out of Einstein. Here, as in her books, she actively shapes science and religion to fit her view.

In a 1982 article L'Engle listed a wide range of science fiction authors who influenced her: H.G. Wells, Jules Verne, E. Nesbit, Ursula LeGuin, John Wyndham, Sylvia Louise Engdahl, Arthur C. Clarke, William Wyndham, and Theodore Sturgeon.¹⁷ Arguing that imagination is central to both science fiction and science itself, she also listed three popular science authors, James Watson, Fred Hoyle and John Gribbin. She notes that Hoyle writes both popular science and science fiction; in Gribbin's case she seems to be familiar only with his popular science writing.¹⁸ Popular science writing thus influenced both L'Engle's understanding of modern science and the contents of her work. In the article, she mentioned Gribbin's *White Holes: Cosmic Gushers in the Universe*, which seems to be featured in *Acceptable*: '[Meg's daughter Polly] read a few pages of the book her grandfather had given her on white holes, cosmic gushers, the opposite of black holes. Her grandparents were certainly seeing to her education.'¹⁹ It is more difficult to find out who may have introduced L'Engle to one of the most memorable scientific elements of *Wrinkle*, the 'tesseract', the four-dimensional analogue to a cube, which her main characters use to travel through space and time. The *OED* gives Charles

¹⁷ L'Engle, 'Childlike Wonder and the Truths of Science Fiction', p. 102, 105, 107, 109, 110.

¹⁸ L'Engle, p. 103.

¹⁹ L'Engle, *An Acceptable Time*, 39.

Howard Hinton's popularization *A New Era of Thought* (1888) as the work from which the term originated,²⁰ and Robert A. Heinlein explored the concept in his 1941 story “—And He Built a Crooked House—”,²¹ but she does not mention having read either. The tesseract was the first scientific element in L'Engle's children's books, and was met with resistance by publishers who did not expect modern physics in a children's book to be successful.

L'Engle freely admitted that it took her a long time to find a publisher for *Wrinkle*, even though she had published several books before.²² One reason for rejection she was given echoes Michael M. Levy's viewpoint mentioned above: 'it was assumed that children would not be able to understand a sophisticated way of looking at time, would not understand Einstein's theories.' However, L'Engle strongly disagreed: 'no theory is too hard for a child so long as it is part of a story; and although parents had not been taught Einstein's $E = mc^2$ in school, their children had been.'²³ Although it is not the case that children are taught $E = mc^2$ in school before GCSE level, to use English educational terminology, the mid-century mathematics curricula did need to lay a foundation for the A-level curriculum, which covers concepts from modern physics.²⁴ L'Engle argues that embedding scientific theories in a story makes it possible to communicate them even to a child.

²⁰ 'Tesseract, N.', *OED Online* (Oxford University Press), accessed 26 November 2015, <http://www.oed.com/view/Entry/199669>; Charles Howard Hinton, *A New Era of Thought* (London: S. Sonnenschein & co., 1888). Abbott's *Flatland* (1884) discusses the concept of a tesseract without coining a specialist term for it.

²¹ Lila M. Harper, 'Mathematical Themes in Science Fiction', *Extrapolation* 27, no. 3 (Fall 1986): 245–69; Robert A. Heinlein, “—And He Built a Crooked House—”, *Astounding Science Fiction*, February 1941.

²² Hearne, 'A Mind in Motion', 29.

²³ L'Engle, 'Childlike Wonder and the Truths of Science Fiction', 109.

²⁴ The English A-level curriculum covers topics such as the photoelectric effect and wave-particle duality. Roger Muncaster, *A-Level Physics*, 1981. 4th ed. (Cheltenham: Nelson Thornes, 2003), 752–61.

Through making both religion and science essential elements that help the protagonists solve the central problem of each novel, L'Engle argued that both should be open to re-interpretation, flexible enough to include each other's newest findings in a unified perspective. Science and religion, she argued, should both be defined by the same open-endedness. She wrote against what Trudelle Thomas describes as 'blind empiricism':

a kind of tunnel vision that occurs when a person relies too heavily on a narrow kind of science. The blind empiricist is the person who focuses only on sensory data and things that can be measured and verified; he cannot see below the surface, cannot use his imagination and cannot think beyond his own categories. The result is a highly limited and one-dimensional view of the world.²⁵

Her writing shows the kind of openness, to both science and that which lies under the surface, that combats this blind empiricism. L'Engle described openness as an essential component of her religious views: 'I heard myself saying, "My religion is subject to change, without notice." I felt I had received a great revelation. That is how it should be, I think, with religion, with science. What we know must always be subject to change as we learn new things.'²⁶ She implies that modern science has been able to direct the outlook of scientists towards this opinion, whereas

until we burst apart the heart of the atom, scientists were looking for the basic building blocks of the universe; something static, in fact. When I was in school and college, science was cold and arrogant. What it did not already know, it was going to discover shortly; basically, science thought it had it made.²⁷

²⁵ Trudelle H. Thomas, 'Spiritual Practices Children Understand: An Analysis of Madeleine L'Engle's Fantasy, *A Wind in the Door*', *International Journal of Children's Spirituality* 13, no. 2 (May 2008): 160, <https://doi.org/10.1080/13644360801965982>.

²⁶ Madeleine L'Engle, 'Subject to Change without Notice', *Theory Into Practice* 21, no. 4 (September 1982): 332-38, <https://doi.org/10.1080/00405848209543027>, p. 334.

²⁷ L'Engle, 333.

Yet the development of quantum physics, although it may not have made science less 'arrogant', proved that science hadn't 'made' it. At the very time L'Engle was in school, physicists were discovering quantum physics, and general relativity was developed just when she headed to college; nearly a century later, quantum physics and general relativity still have not been unified into a coherent theory. L'Engle's exposure to the 'arrogant' science of her youth led her to the viewpoint that in science as well as religion, resistance to change will create zeal, which is to be prevented and avoided at all costs.²⁸

L'Engle links science and religion in her stories through a shared goal of openness to change. By making science the instigator of the adventure which leads to a religious conclusion, she negates both the apparent opposition between science and religion to be found in historical cases from Galileo and Giordano Bruno onwards, and the idea that science possesses the ultimate answers: 'I have never seen any conflicts,' she claimed. 'It seems to me that anything science can uncover simply gives us a wider view of the universe and of the Maker. Conflict is where you cling to an idea without allowing it to change or grow.'²⁹ Science can affirm religion, she argues: 'to me, particle physics and quantum mechanics are extremely theological because they are dealing with the nature of being, so they are just as theological as a tome on morals.'³⁰ Science and religion ask the same questions, she suggests, and address the same problems; in her works, only the application of both will lead to a happy ending. In *Wrinkle*, Meg's father is one of the world's most brilliant minds, and he has discovered the possibility

²⁸ L'Engle, 334.

²⁹ Hearne, 'A Mind in Motion', 31.

³⁰ Hearne, 31.

of tessering, but his children, motivated by love and limited in their scientific knowledge, must come to rescue him and finish his work. Starting from science, L'Engle leads the reader to a religious conclusion, regarding the necessity for love, compassion, and a Creator. Her books argue that even the most modern science can only offer the beginnings of understanding, and a full comprehension and utilization of this scientific knowledge can only be made through opening up to religious principles.

Quantum physics is central to the Time Quintet as a whole, although the word 'quantum' does not appear in her work until *Waters*. Notably, this instalment was published in 1986, at the time of what Elizabeth Leane has termed the 'popular science boom' of the final quarter of the twentieth century. This 'boom' was instigated by the publication of several best-selling popularizations of quantum physics such as Steven Weinberg's *The First Three Minutes* (1977), Gary Zukav's *The Dancing Wu Li Masters* (1979) and the works of Richard Feynman.³¹ The more widespread use of and familiarity with the term 'quantum' during this period may have influenced L'Engle's decision to make use of it in her later works, in order to make the scientific concepts that were already present in her works fit the contemporary popular discourse. Two concepts that are key to quantum physics were already a recurring theme in the series from the first instalment onwards: that of multidimensional space- and time-travelling, and that of scale changes.

L'Engle uses the concept of more than three spatial dimensions as a scientific underpinning to the common fantasy trope of inter-world travelling; as explained be-

³¹ Leane, *Reading Popular Physics*, 1.

low, Pullman uses the many-worlds interpretation of quantum physics to the same effect. Space and time travel can be accomplished via a tesseract: just as the two ends of a straight line drawn on a two-dimensional sheet of paper can be brought close together through folding the paper in the third dimension, so can two ends of four-dimensional spacetime be brought together through bending in the fifth dimension. *Wrinkle* explains this concept in the largest infodump to be found in the quintet, in an analogical format reminiscent of popular science books: the first half of Chapter Five, 'The Tesseract', is devoted to explaining what a tesseract is, aided by Mrs Who's skirt and four illustrations. Calvin and Charles Wallace immediately understand, but Meg, who is a bit slower, needs further explanation. Meg's slowness seems to be an artificial insertion here, as she has earlier on in the book proven to be a very adept mathematician who can help the older Calvin with his maths homework.³² The group doesn't leave until everyone understands the concepts behind 'tessering,' travelling in space and time through the fourth spatial dimension. The children are subsequently nearly killed as they accidentally land on a two-dimensional world, a brief reference to *Flatland* which is likely to be picked up only by parents reading the book to their children.

Just as religion should be flexible according to L'Engle, the work of the scientist parents in the Quintet is similarly open to re-interpretation as scientific understanding changes. The professions of the Murrys are described loosely enough that L'Engle can attribute certain fields or kinds of research to them depending on what suits the current book. In *Wrinkle*, Mr Murry is referred to both as a theoretical physicist and an

³² L'Engle, *A Wrinkle in Time*, 14, 84–88.

astronaut; in *Acceptable* he is an astrophysicist instead.³³ In *Wind*, Mrs Murry, a biologist, postulates the existence of farandolae, lifeforms so small that ‘even the most powerful micro-electron microscope can’t show them.’³⁴ By the time *Waters* and *Acceptable* are written, L’Engle seems to have realized that lifeforms cannot exist at this scale, of individual particles, so she drastically changes the history of Mrs Murry’s career: the diegetic science is influenced by advances in extradiegetic science. In *Waters*, Mrs Murry ‘was a scientist who had won the Nobel Prize for discovering particles so small they were scarcely conceivable’: she has now become a quantum physicist.³⁵ The farandolae, living creatures, have now become particles. The ‘hard’ and the ‘soft’ sciences are not gendered in the Time Quintet: the female scientist is comfortable in both fields, and Meg grows up to be a mathematician.³⁶

The role of their parents’ research in the lives of the Murry children shows how L’Engle’s series treats science and religion as individual activities, rather than as the product of institutions. Scientists in the Time Quintet make their most important discoveries individually, at home, where their children can access the equipment. This approach to science harks back to nineteenth-century popular science works that brought science into the home in a similar way: in Jane Marcet’s *Conversations on Chemistry*, for instance, the young protagonists are able to interact with the equipment that their teacher, Mrs B., provides for them at their home.³⁷

The Murrys do not seem to work in a university; Mrs Murry combines motherhood with scientific enterprise by having a laboratory as part of her countryside house,

³³ L’Engle, *A Wind in the Door*, 37; L’Engle, *Many Waters*, 278; L’Engle, *An Acceptable Time*, 17.

³⁴ L’Engle, *A Wind in the Door*, 23.

³⁵ L’Engle, *Many Waters*, 289.

³⁶ L’Engle, *An Acceptable Time*, 119.

³⁷ Marcet, *Conversations on Chemistry*.

from which she performs the research in cellular biology that shapes the plot of *Wind* and for which she wins the Nobel Prize referred to in *Waters*. In *Waters*, she owns scientific equipment that is rather too expensive for two scientists: ‘There was now a formidable-looking [electron] microscope, some strange equipment only their mother understood, and an old-fashioned Bunsen burner, over which, on a homemade tripod, a black kettle was simmering’ – the kettle contains stew for the family dinner – and the lab turns out to contain a tesseract teleporter too.³⁸ The lab also serves as a kitchen and a family gathering place, an idea that would likely terrify professional chemists and biologists. The lab/kitchen thus serves as a microcosm for the novels’ merging of the personal and domestic with the scientific issues that have universe-wide ramifications.

Mr Murry, a world-famous scientist, ‘most of the time [...] works alone but some of the time [...] was at the Institute for Higher Learning in Princeton. [...] Then he did some work for the government’.³⁹ L’Engle envisioned a similar future, without fixed affiliations, for Meg and Calvin O’Keefe. As she observes in an interview: ‘In the book I’m writing now, Meg is explaining to one of her kids that the reason they don’t have much money is that Calvin is working alone. He’s not with a university getting grants.’⁴⁰ Bringing science into a domestic setting allows the Murry children to hear about the latest developments their parents have made, and to use this knowledge in their own adventures.

The spatial arrangement of science within institutions normally ensure that cutting-edge scientific knowledge is inaccessible to children. Both the Time Quintet and

³⁸ L’Engle, *Many Waters*, 6–10.

³⁹ L’Engle, *A Wrinkle in Time*, 58.

⁴⁰ Hearne, ‘A Mind in Motion’, 30. As this interview was conducted in 1998, L’Engle seems to be referring to a novel that was never published, ‘which is about Meg in her 50s’ (31). No Murry/O’Keefe books were published after *Acceptable* (1989).

His Dark Materials require a significant plot contrivance in order to give children access to this knowledge: whereas the Murry children are given normal childhoods, but their parents conduct research in the unusual setting of the home rather than within the scientific community, Pullman's Lyra has to be given an unusual childhood within the scientific community rather than within a family. Access to science is a common problem in both popular science books and science fiction for children, which is usually resolved in the way adopted by L'Engle: the scientific knowledge is passed on via a scientist close to or within the family. The George series discussed in the previous chapter relies on a similar arrangement: Eric conveniently hosts a conference at his house, and keeps his space-travelling supercomputer at home, rather than at a lab.⁴¹ Pullman is one of the few authors who manages to maintain the institutional element of science in a work for children.

Since science and religion operate together in the novels, religion is similarly de-institutionalized. Although it is clear that L'Engle's protagonists are Christian, the Murrays and Calvin never visit a church. L'Engle herself did not identify with a particular church, and emphasized that she opposed the breaking up of Christendom into different churches:

We human beings far too often tend to codify God, to feel that we know where he is and where he is not, and this arrogance leads to such things as the Spanish Inquisition, the Salem witch burnings, and has the result of further fragmenting an already broken Christendom.⁴²

In the Time Quintet, religious views are instead shaped by individual conversations, teachings, and memories. In *Acceptable*, for instance, a new character is introduced, the

⁴¹ Hawking and Hawking, *George's Secret Key to the Universe*.

⁴² Madeleine L'Engle, *Walking on Water: Personal Reflections* (1980; repr., Herts: Lion Publishing, 1982), 28.

retired Bishop Nason Colubra.⁴³ His former affiliation is never mentioned; through the combination of his advice and personal views, and the Murrays' scientific knowledge, Polly is able to understand what is going on when she discovers she can travel between the present and three millennia ago.

Gwyneth Jones claims that '[t]he science content of [*Wrinkle*] may be slight, and always subordinate to L'Engle's [*sic*] particular brand of ideological metaphysics, but it does feature a girl who is at home – notionally at least – with maths and physics.'⁴⁴ I would argue instead that the science content of the work is quite substantial, both in terms of depth – as the lengthy explanation of tesseracts in *Wrinkle* shows – and in terms of breadth – L'Engle introduces her readers to concepts from physics, biology, and mathematics over the course of the series. The science content of *Wrinkle* was sizeable enough to make the book appear on a 'science interest inventory' list in an article that argued that teachers should pay more attention to popular science books as enjoyable means of conveying scientific knowledge.⁴⁵ Nonetheless, it is indeed the case that the science is subordinate to L'Engle's 'ideological metaphysics'. L'Engle makes the same argument about openness with regard to both science and religion, but that does not make the two equal to each other.

There is a definite hierarchy, and a fixed role, for the scientific, the divine, and the fantastical in each work: the main argument concerns the divine; the fantastical setting is necessary for the adventure to take place; and the scientific content forms the foundation. The story itself is mostly fantastical. The scientific seeds are sown by the

⁴³ L'Engle, *An Acceptable Time*, 13.

⁴⁴ Gwyneth Jones, 'Writing Science Fiction for the Teenage Reader', in *Where No Man Has Gone Before: Women and Science Fiction*, ed. Lucie Armitt (London: Routledge, 1991), 155–77, p. 167–168.

⁴⁵ Janice A. Dole and Virginia R. Johnson, 'Beyond the Textbook: Science Literature for Young People', *Journal of Reading* 24, no. 7 (April 1981): 579–82.

parents and their discoveries, but their relevance is imparted by supernatural beings and events. All works begin with a scientific concept being introduced: the tesseract in *Wrinkle*, *Planet* and *Acceptable*, farandolae in *Wind*, and virtual particles in *Waters*; the adventures cannot take off, however, until a fantastical intervention takes place that enables them to engage with the concept. In *Wind*, for instance, the children are first introduced to the concept of farandolae through Mrs Murry's research: she is trying to prove their existence. The adventure starts when Meg, Calvin and Charles Wallace meet Blajeny, who teaches them to communicate telepathically, and the cherubim Proginoskes, who knows the names of all the stars but does not know love. Blajeny is able to transport them through space and time. Progo, as Proginoskes is soon called, is coupled with the children despite his feeling vastly superior to them, as Blajeny explains that they need to learn from each other in order to complete the tasks that lie ahead.⁴⁶

Since the religious messages are mostly invisible at the start of each novel, the readers slowly discover along with the protagonists how central religious ideas are to the successful resolution of the adventure. In *Wind*, arguably the least explicitly religious of the five books, the message is about love: Blajeny sets Meg three tasks in which she must learn to apply the 'love thy neighbours' proverb, even to the schoolmaster she hates. Progo's knowledge is not enough, and must be complemented by love. As he learns this, he sacrifices himself in order to save everyone else. The children have explored the inside of mitochondria, but it is the saving grace of an angel which creates the happy ending.

⁴⁶ L'Engle, *A Wind in the Door*, 61–62.

L'Engle's series shows how a Christian author was able to write science fiction with a religious message by means of an open-minded approach to both science and religion. Her works make use of modern physics in order to take up this position: she is working in a recognizable vein of connecting quantum physics and religion.⁴⁷ She uses fantasy as a bridge between science and religion to make the connection explicit, allowing the child protagonists to meet both scientific concepts and religious figures and ideas in the fantasy world. Philip Pullman, an avowedly nonreligious author, similarly addresses these intersections, yet shows a negative side to both: science and religion are not opposed, but can be employed to undermine as well as support each other.

Philip Pullman: Science and Religion as Democratic

Northern Lights (1995) was the first instalment in the *His Dark Materials* trilogy by the British author, and Oxford graduate, Philip Pullman (1946).⁴⁸ The novel presents a fantasy world in which humans are accompanied by the animal embodiment of their souls, called dæmons. Eleven-year-old Lyra and her dæmon Pantalaimon grow up orphaned at Jordan College, Oxford. Lyra leaves Oxford to find her missing friend Roger, with the help of an alethiometer, a truth-telling device that is powered by a mysterious substance called Dust. Lyra's uncle, Lord Asriel, who is affiliated with Jordan College, is researching Dust, which seems to fall out of the sky onto adults. As it does not touch children, Dust is considered the physical manifestation of original sin. In this world, institutional science and institutional religion are intertwined and dangerous. A

⁴⁷ A comprehensive overview of such connections is given in John Polkinghorne, *Quantum Physics and Theology: An Unexpected Kinship* (New Haven: Yale University Press, 2007).

⁴⁸ In the United States, the first instalment was published under the title *The Golden Compass*.

Church scientist, Mrs Coulter, conducts experiments on children to see if separating them from their dæmons can prevent original sin. Lord Asriel discovers that the death of a child, Roger, through separation from his daemon, can open a portal between worlds, and Lyra follows him into the city of Cittàgazze.

The Subtle Knife (1997) shows the reader the parallel worlds at which *Northern Lights* had hinted. Twelve-year-old Will Parry from the 'real' Oxford, on the run after having committed murder, finds a window in the sky which also leads to Cittàgazze. He runs into Lyra and obtains the 'subtle knife', a knife which can cut these windows between worlds. Will and Lyra go back to Will's Oxford, where research on Dust is also being done: they meet the theoretical physicist Mary Malone, a former nun, who shows the reader that Dust is a real scientific phenomenon: Malone works at the 'Dark Matter Research Unit'.

In the concluding book, *The Amber Spyglass* (2000), Dr Malone leaves her institution and travels to yet another world, where she meets a new conscious lifeform, the mulefa. She discovers that Dust indeed originates in original sin, and that consciousness cannot function without it: the Fall of Man was not a negative event. Indeed, in order to save the world, Lyra must act as a second Eve and fall in love, which the Church tries to prevent by attempting to murder her. The Church at the same time fights a war: Lord Asriel is determined to democratize religion by overthrowing the Kingdom of Heaven and replacing it with a Republic of Heaven. Lyra and Will travel to the land of the dead, to apologize to Roger and to free the dead into the world of the mulefa. There,

Mary Malone acts as the snake, showing Lyra and Will what it means to fall in love. When the two kiss, the second Fall is accomplished.⁴⁹

His Dark Materials is thus partly a rewriting of *Paradise Lost*; the trilogy's title is taken from a passage which also forms the motto to *Northern Lights*.⁵⁰ Pullman's trilogy gives a more positive ending to *Paradise Lost*: the Fall was a fortunate event. In *The Amber Spyglass*, the mulefa theology is shown to include a Genesis-like story, but without the negative implications: gaining knowledge is not considered to be a fall from a better state. As Pinsent points out, if there is no Fall, there is no place for a Christ-like redeemer in the trilogy.⁵¹ *Paradise Lost* itself has also been interpreted as a positive perspective of the Fall: Arthur O. Lovejoy's 1937 interpretation of the work as presenting a 'Paradox of the Fortunate Fall' remains influential. Lovejoy places the work in a long tradition of positive interpretations of the Fall, claiming that the archangel Michael's prediction of the Second Coming and the Final Judgment can be interpreted as a fortuitous outlook for the future.⁵² In Book 12, Adam replies thus to Michael:

O goodness infinite, goodness immense!
That all this good of evil shall produce,
And evil turn to good; more wonderful
Then that by which creation first brought forth
Light out of darkness! full of doubt I stand,
Whether I should repent me now of sin

⁴⁹ Shockingly, passages from *The Amber Spyglass* have been cut in the US version at the points where references to 'Lyra's budding sexuality' were made, which significantly hinders Pullman scholarship in the US. (Richard Corliss, 'What Would Jesus See?', *Time*, 8 December 2007, <http://content.time.com/time/arts/article/0,8599,1692926,00.html>.)

⁵⁰ Tommy Halsdorf and Catherine Butler, 'Introduction', in *Philip Pullman: His Dark Materials*, ed. Catherine Butler and Tommy Halsdorf (Basingstoke: Palgrave Macmillan, 2014), 1–18; John Milton, 'Paradise Lost (1667)', in *The Poetical Works of John Milton*, ed. H. C. Beeching (London: Oxford University Press, 1941), 173–448, p. 223 (II: 910–919).

⁵¹ Pat Pinsent, 'Philip Pullman's "Religious Reaction against Religion" in *His Dark Materials*', in *Philip Pullman: His Dark Materials*, ed. Catherine Butler and Tommy Halsdorf (Basingstoke: Palgrave Macmillan, 2014), 19–35, p. 25, 30–31.

⁵² Arthur O. Lovejoy, 'Milton and the Paradox of the Fortunate Fall', *ELH* 4, no. 3 (September 1937): 161–79, <https://doi.org/10.2307/2871531>.

By mee done and occasiond, or rejoice
 Much more, that much more good thereof shall spring,
 To God more glory, more good will to Men
 From God, and over wrauth grace shall abound.⁵³

Justice and mercy, after all, are impossible to conceive of without sin. However, Lovejoy's viewpoint has also been met with criticism. Dennis Danielson points out that even though the Final Judgment will bring bliss, humanity would have been even happier if the Fall had not happened at all, citing Milton's own words to support this theory:⁵⁴ 'Happier, had it suffic'd him to have known/Good by himself, and Evil not at all.'⁵⁵ Pullman treats the Fall as more unambiguously good: if the second Fall does not occur, the mulefa will soon die. However, Falconer points out that the consequences for his Adam and Eve, Will and Lyra, are much more painful: whereas Milton's Adam and Eve could at least try to find their way 'hand in hand',⁵⁶ Will and Lyra have to live in separate, closed, parallel universes.⁵⁷

Halsdorf and Butler assert that Pullman based the character of Lord Asriel on Milton's depiction of Satan.⁵⁸ Again, Pullman's treatment is more favourable than Milton's: Asriel succeeds in his war against the Authority, and although he ends up falling into the abyss, like Satan, this fall constitutes an essential step towards winning this war, as he and Mrs Coulter drag the tyrant angel Metatron down with them. This positive interpretation of Satan's role, too, stems from a longer tradition. Andrew M. Butler argues that William Blake interpreted Milton's Satan as 'a hero who failed'; however,

⁵³ Milton, 'Paradise Lost (1667)', p. 443-44 (XII: 469-478).

⁵⁴ Dennis Danielson, 'The Fall and Milton's Theodicy', in *The Cambridge Companion to Milton*, ed. Dennis Danielson, 2nd ed. (Cambridge: Cambridge University Press, 1989), 144-59, p. 156.

⁵⁵ Milton, 'Paradise Lost (1667)', p. 411 (XI: 88-89).

⁵⁶ *Ibid.*, 448 (XII: 648).

⁵⁷ Falconer, *The Crossover Novel*, 94.

⁵⁸ Halsdorf and Butler, 'Introduction', 4.

as Butler explains, it is not clear to the reader whether in Lyra's world Satan won or lost in his rebellion against God.⁵⁹

Science is central to Pullman's renegotiation of religion. Surprisingly, very few critical readings of Pullman's trilogy address the importance of several concepts of modern physics within it. It wasn't until 2014 that a critical reading of the trilogy engaged explicitly with the scientific dimension of the works.⁶⁰ However, Waller focuses on the manner in which scientific inquiry and the concept of the scientist are treated in a more general manner in the trilogy; her essay is not about the science itself. Despite its title, Arthur B. Markman's 2005 essay only covered technology, not science.⁶¹

Anne-Marie Bird points out the parallel between Dust and dark matter, but her explanation is incorrect:

Dust appears to correspond to the scientific phenomenon known as cosmic dust: the small particles of baryonic matter that are distributed throughout space and which, according to current theories of cosmology, make up at least ninety percent of the mass of the universe.⁶²

Cosmic dust, which consists of baryonic matter, is an entirely different phenomenon from dark matter and accounts for only 1% of interstellar mass.⁶³ Bird also claims that

⁵⁹ Andrew M. Butler, 'The Republic of Heaven: The Betrayal of Philip Pullman's His Dark Materials Trilogy', in *Children's Fantasy Fiction: Debates for the Twenty First Century*, ed. Nickianne Moody and Clare Horrocks (Liverpool: Liverpool John Moores University, 2005), 292.

⁶⁰ Alison Waller, 'The Pursuit of Knowledge: Scientific Enquiry in His Dark Materials', in *Philip Pullman: His Dark Materials*, ed. Catherine Butler and Tommy Halsdorf (Basingstoke: Palgrave Macmillan, 2014), 58–75.

⁶¹ Arthur B. Markman, 'Science, Technology and the Danger of Dæmons', in *Navigating The Golden Compass: Religion, Science & Dæmonology in Philip Pullman's His Dark Materials*, ed. Glenn Yeffeth (Dallas, TX: BenBella Books, 2005), 61–70.

⁶² Anne-Marie Bird, "'Without Contraries Is No Progression": Dust as an All-Inclusive, Multifunctional Metaphor in Philip Pullman's "His Dark Materials"', *Children's Literature in Education* 32, no. 2 (2001): 111–23.

⁶³ For research into cosmic dust, see e.g. C. W. McCracken, W. M. Alexander, and M. Dubin, 'Direct Measurement of Interplanetary Dust Particles in the Vicinity of Earth', *Nature* 192, no. 4801 (4 November 1961): 441–42, <https://doi.org/10.1038/192441b0>.

'Pullman is suggesting that every elementary particle of Dust contains the entire universe,'⁶⁴ yet an analysis of the scientific concepts used by Pullman show clearly that this is not the case. She supports her argument with the following claim:

In the second book of Pullman's trilogy, the rebellious atoms of *Paradise Lost* are organised and arranged further, evolving into a system of classification that involves the entire spectrum ranging from pure matter to pure spirit—'Dust,' 'dark matter' 'Shadows,' 'shadow-particles,' 'particles of consciousness' [...] and 'rebel angels' [...].⁶⁵

However, Pullman does not imply a 'classification' here, as all these names refer to the exact same phenomenon: Bird takes these names from different scientific and non-scientific registers that are employed in the various parallel worlds throughout the trilogy.

Mary and John Gribbin's *The Science of Philip Pullman's His Dark Materials* is a popular science tie-in book for children, which attempts to explain the concepts from quantum physics as used by Pullman to a young readership. John Gribbin, an astrophysicist and science writer, had previously published the successful quantum physics popularization *In Search of Schrödinger's Cat*, discussed in Chapter 1, in which he endorses the many-worlds interpretation. In this popularization for children, he similarly favours this interpretation: after explaining the Copenhagen interpretation, the Gribbins write, 'The best explanation is another quantum interpretation, called the Many Worlds Interpretation.'⁶⁶ Although she does not mention any interpretations by name, L'Engle might also have been biased in favour of many-worlds, as Gribbin is an important scientific influence on her, as shown above.

⁶⁴ Bird, "Without Contraries Is No Progression", 114.

⁶⁵ Bird, 114.

⁶⁶ Mary Gribbin and John Gribbin, *The Science of Philip Pullman's His Dark Materials* (New York: Laurel-Leaf, 2005), 91.

One reason for the neglect of the scientific element in Pullman criticism may be that the anti-Christian standpoint of the books, both in its interpretation of the Fall as positive and the death of a being who calls himself God in *The Amber Spyglass*,⁶⁷ has drawn nearly all of the critics to address Pullman's theology as the focal point of their analyses: Lenz and Scott's essay collection, for instance, contains no essays that focus on the scientific content.⁶⁸ Waller's is the only essay about science in Butler and Halsdorf. Yet an analysis of the way in which both science as a whole and specific concepts from modern physics are used in *His Dark Materials* can show that science is as important a driving factor for the narrative as theology. As Waller argues, the trilogy emphasizes the virtues of knowledge above ignorance in many different forms: the scientific is one alongside 'philosophical, poetic, sexual' and other forms of knowledge.⁶⁹ Pullman makes the same claim about all these different forms of knowledge: they can be dangerous in the wrong hands, and especially when handled by ignorant minds.

Rosemary R. Johnston describes Pullman's 'sense of time and space' as 'beguilingly hard to locate.'⁷⁰ Lyra's world is in many ways reminiscent of the steampunk genre, which relies on a Victorian setting: women are not allowed to take part in many aspects of University life, and live in separate colleges; transportation takes place by steam train, hot air balloon, or zeppelin; 'anbaric' (electric) light is still a novelty and naphtha lamps are much preferred. However, a focus on the science can once more

⁶⁷ Pullman, *The Amber Spyglass*, 412. This being is not the actual Creator, but an angel who became an usurper, as the angel Balthamos explains (31).

⁶⁸ Millicent Lenz and Carole Scott, eds., *His Dark Materials Illuminated: Critical Essays on Philip Pullman's Trilogy*, Landscapes of Childhood (Detroit: Wayne State University Press, 2005).

⁶⁹ Waller, 'The Pursuit of Knowledge', 58.

⁷⁰ Rosemary Ross Johnston, 'Pullman, the Idea of Soul, and Multimodal "Seeability" in *Northern Lights* and the Film *The Golden Compass*', in *Philip Pullman: His Dark Materials*, ed. Catherine Butler and Tommy Halsdorf (Basingstoke: Palgrave Macmillan, 2014), 40.

provide clarification. The science of Lyra's world is much more up to date than the technology and society, and resembles post-1970s knowledge: uranium is mined for 'atomcraft', the existence of photons is commonly known, and at age twelve Lyra 'knew about atoms and elementary particles, and anbaromagnetic charges and the four fundamental forces'.⁷¹ The suggestion is made that technology is adopted only partially and haphazardly because the Enlightenment never took place in this world; instead, John Calvin became the last pope.

Though the *His Dark Materials* trilogy is a mix of science fiction and fantasy, it cannot be considered a 'scientific fantasy'. In Chapter 3 I argued that the scientific fantasy genre is a form of science popularization, whereas the *His Dark Materials* trilogy is not written in order to teach the readers about physics. There are certainly didactic elements in the book, with respect to morality in science and religion, but the didacticism does not extend to scientific concepts. No explanations are given for the scientific phenomena that occur in the book, although scientific concepts play an important role in the trilogy. The reader is free to verify that the scientific concepts are real, just as the reader is free to go and see the trepanned skulls which Lyra looks at during her visit to the Pitt Rivers Museum in Will's Oxford. Equally importantly, Pullman goes beyond an exposition of science, but does not indicate to the reader at which point he steps beyond the boundaries of scientific knowledge. Pullman addresses the reader's curiosity and gives them the freedom to follow it up or not. In the introduction to Gribbin and Gribbin, Pullman downplays the importance of science in his writing:

I wasn't writing about science, after all. I was writing about Lyra, and Will, and Mrs Coulter and Lee Scoresby and Mary Malone and all the other characters;

⁷¹ Pullman, *Northern Lights*, 83.

and although I did try to get a bit of science in, and to get it right, it was very much there as a background, as a sort of stage set for the story to take place in front of. [...] What I did try to do was get the science right – though not for a scientific purpose: for a storytelling purpose.⁷²

Though detailed knowledge of specific scientific facts or concepts may not be necessary for enjoying the story, science itself, its methods and approaches, is essential to the plot; the use of real science strengthens Pullman's argument as applying to the reader's world. What Pullman calls the background or the stage is essential for the story as a whole, though it may not be essential for individual characters: scientific knowledge is indeed not essential for the two child protagonists, and by extension, not important for a young reader. Pullman is trying to evoke a sense of wonder purely for its own sake, whereas many popular science works attempt to employ this same sense of wonder in order to educate the reader more easily.

Dark Matter

Three aspects of modern physics play an important role in *His Dark Materials*: the many-worlds interpretation of quantum physics, which allows for the possibility of there being multiple parallel worlds; quantum entanglement, which is used as a means of instant communication between parallel worlds; and dark matter. This dark matter, or Dust, is one of the most important novae of the work.

'Dust' is the colloquial name for the material, taken from the Bible, as Lord Asriel explains to Lyra: '*for dust thou art, and unto dust thou shalt return.*'⁷³ Officially, the phenomenon is called 'Rusakov particles' in Lyra's world, which are '[e]lementary particles

⁷² Philip Pullman, 'Science: A Very Short Introduction', in *The Science of Philip Pullman's His Dark Materials*, by Mary Gribbin and John Gribbin (New York: Laurel-Leaf, 2005), xii–xix, p. xvii.

⁷³ Pullman, *Northern Lights*, 371.

that do not interact in any way with others – very hard to detect.⁷⁴ Pullman uses the fact that contemporary physics knows very little about dark matter to equate it to Dust. Dark matter is something which comprises 85% of the mass in our universe, but of which we know very little, aside from the fact that it cannot be made of regular, baryonic, matter or antimatter.⁷⁵ The Dust particles are the ‘dark materials’ the trilogy is named after; Pullman derives this term from Milton, who uses the concept of ‘dark materials’ as a ‘metaphor for the mass of unformed primal matter left over from the construction of the universe’.⁷⁶ Pullman brings together Milton’s concept with the dark matter of modern cosmology, which we do not understand, even though most of the universe consists of it.

There is one important difference between Dust and dark matter as we know it: Rusakov particles are conscious and ‘seem to be attracted to human beings’.⁷⁷ It is Dust that makes Lyra’s alethiometer function, and initially Lyra thinks it is the work of spirits – an understandable explanation in a world where ‘night-ghasts’ are real spirits that haunt people at night. The Church within the series similarly connects Dust to a spiritual origin, that of the Fall of Man, since Dust is not attracted to ‘innocent’ children. Such a position contradicts the viewpoint of the Catholic Church: the *Catechism of the Catholic Church* reads, ‘Born with a fallen human nature and tainted by original sin, children also have need of the new birth in Baptism to be freed from the power of darkness.’⁷⁸ In Lyra’s world, there is a real and absolute difference between children and

⁷⁴ Pullman, 89.

⁷⁵ Evalyn Gates, *Einstein’s Telescope: The Hunt for Dark Matter and Dark Energy in the Universe* (London: W.W. Norton & Co, 2009), 159.

⁷⁶ Bird, “‘Without Contraries Is No Progression’”, 112.

⁷⁷ Pullman, *Northern Lights*, 89; Pullman, *The Subtle Knife*, 248.

⁷⁸ ‘Catechism of the Catholic Church - Part 2, Section 2, Chapter 1, Article 1’, Saint Charles Borromeo Catholic Church, accessed 14 December 2015, <http://www.scborromeo.org/cc/p2s2c1a1.htm#1250>.

adults: when someone reaches adulthood, their *dæmon* can no longer change shape. Despite this absolute distinction between childhood and adulthood, even in this world, Lesnik-Oberstein's claim that 'the "child" is a *construction*, constructed and described in different, often clashing, terms'⁷⁹ still applies. Pullman's Church tries to superpose an absolute distinction between innocence and sin onto this transition from child to adult. Sin has previously been likened to dust: an allegory of 'dust' as the embodiment of original sin also appears in John Bunyan's *Pilgrim's Progress*, though it is portrayed in an unambiguously negative manner there.⁸⁰ Pullman, however, shows that the transition from childhood to adulthood does not imply becoming sinful, but rather, becoming knowledgeable.

The scientific nature of Dust is highlighted by Pantalaimon, who insists that there might be a more scientific explanation for the alethiometer's functioning: it might be moved by elementary particles, he suggests, in the same way that a 'photo-mill' moves when light hits it.⁸¹ As Gribbin and Gribbin emphasize, Lyra's world is understood better by understanding its science, in the same way that our world would seem magical to a person from Lyra's world who has no knowledge of the science that underlies it.⁸² And yet, it is Mary, the real-world scientist who does not yet believe in night-ghasts or *dæmons*, who discovers the connection between Dust and religion: when she finds out how to communicate with the particles, they identify themselves as

⁷⁹ Lesnik-Oberstein, *Children's Literature*, 9.

⁸⁰ Shelley King, "'Without Lyra We Would Understand Neither the New nor the Old Testament': Exegesis, Allegory, and Reading *The Golden Compass*", in *His Dark Materials Illuminated: Critical Essays on Philip Pullman's Trilogy*, ed. Millicent Lenz and Carole Scott (Detroit: Wayne State University Press, 2005), 106–24, p. 120.

⁸¹ Pullman, *Northern Lights*, 149. The description of the 'photo-mill' resembles that of a Crookes radiometer, which was invented in the nineteenth century.

⁸² Gribbin and Gribbin, *The Science of Philip Pullman's His Dark Materials*, 34.

'angels'.⁸³ However, this self-identification of Dust is difficult to reconcile with the appearance of another kind of beings that call themselves angels: Baruch and Balthamos, vaguely humanoid beings, visible at dusk and dawn, who seem to have a homosexual relationship.⁸⁴ Baruch was once a human, Balthamos was not; Balthamos refuses to tell Will how human beings can become angels.⁸⁵ They seem to be related to the ghosts of the dead, but with the ability to hold themselves together.

Quantum Entanglement

The second concept from quantum physics around which Pullman structures his narrative, which does not appear until *The Amber Spyglass*, is that of quantum entanglement. In this third novel, a new sentient species is introduced: the Gallivespians, humanoids that are a hand-span tall and are accomplished spies. Their method of communicating with each other, the 'lodestone resonator', is first mentioned several times without an explanation; the reader is told no more than that the resonator allows people to learn very quickly what is happening elsewhere, and apparently resembles a tiny string instrument.⁸⁶ The resonator seems entirely unremarkable until the Gallivespian Tialys reveals that it can communicate between parallel worlds.⁸⁷ Finally, when Lyra is saved from being abducted and returns to the story, her curiosity reveals the functioning of the resonator to the reader. As Tialys explains to her:

'Your scientists, what do you call them, experimental theologians, would know of something called quantum entanglement. It means that two particles can exist that only have properties in common, so that whatever happens to one happens to the other at the same moment, no matter how far apart they are. Well,

⁸³ Pullman, *The Subtle Knife*, 248.

⁸⁴ Pullman, 323; Pullman, *The Amber Spyglass*, 12. Pullman stated he did not know how Dust as angels and Baruch and Balthamos as angels were related. Personal communication, 6 May 2016.

⁸⁵ Pullman, *The Amber Spyglass*, 16.

⁸⁶ Pullman, 59, 117, 145, 167.

⁸⁷ Pullman, 172.

in our world there is a way of taking a common lodestone and entangling all its particles, and then splitting it in two so that both parts resonate together.’⁸⁸

Although Gribbin and Gribbin correctly claim that ‘quantum entanglement is real science,’⁸⁹ a theory which has been recently confirmed,⁹⁰ Tialys’s explanation is incorrect. Entanglement implies correlation, rather than commonality: if an entangled system of two particles is known to have zero spin, and the first particle is measured to be spin down, then the second particle must necessarily be spin up, rather than be identical to the first particle. Since deliberate entanglement has never been achieved in anything other than photons, the second part of Tialys’s explanation is obviously fantastical. In this passage, the difference between incorrect science and science fiction becomes clear: whereas Tialys’s explanation of entanglement is clearly wrong, the concept of a lodestone resonator could be considered an extrapolation, the like of which may one day be real (although by using a lodestone, Pullman seems to have conflated entanglement and magnetism). Quantum entanglement would indeed still hold if one of the entangled particles is in a different parallel world from the other, so it is a scientifically sound and internally consistent way to communicate between worlds.

The Many-Worlds Interpretation

Pullman makes use of the many-worlds interpretation of quantum physics to ground his inter-universe travelling in a scientific theory. As Marie-Laure Ryan notes, travelling between worlds is a common trope in the fantasy genre, in which no explanations are normally given for the reason why this travel is possible.⁹¹ In *His Dark Materials*,

⁸⁸ Pullman, 175–76.

⁸⁹ Gribbin and Gribbin, *The Science of Philip Pullman’s His Dark Materials*, 169.

⁹⁰ B. Hensen et al., ‘Loophole-Free Bell Inequality Violation Using Electron Spins Separated by 1.3 Kilometres’, *Nature* 526, no. 7575 (21 October 2015): 682–86, <https://doi.org/10.1038/nature15759>.

⁹¹ Ryan, ‘From Parallel Universes to Possible Worlds’.

on the other hand, this travel is scientifically validated through reference to Everett's work: 'Everett you remember, 1957 or thereabouts,' notes Sir Charles Latrom when he demands that Mary Malone and her colleague investigate this topic as a condition of their funding.⁹² Pullman became acquainted with the many-worlds interpretation through, among other sources, an article in *Scientific American*⁹³ and an apparently specialist lecture given by quantum physicist David Deutsch, as he explains in the introduction to Gribbin and Gribbin:

In the case of parallel worlds, I read as much as I could find about the matter; I went to a lecture by David Deutsch, a scientist who has done a great deal of research into the subject; and although I didn't understand very much, I hope I managed to absorb enough of the arguments to make the reader feel that the background was solid enough not to fall over when anyone leant against it.⁹⁴

I have not been able to identify the title, date or contents of this lecture, but it must have taken place before 1995, the publication year of *Northern Lights*. Notably, this was before Deutsch published his first popularization, *The Fabric of Reality* (1997), in which he popularizes the many-worlds interpretation; the lecture may have already contained concepts later written up in this book. Pullman read Deutsch's popularization when it came out, but it could not have influenced either *Northern Lights* or *The Subtle Knife*.⁹⁵

Pullman makes the dæmon Kaisa explain the scientific background to Lyra and the readers. The worlds overlap everywhere, without people being aware of them in any of the regular four dimensions:

⁹² Pullman, *The Subtle Knife*, 242.

⁹³ Philip Pullman, Personal communication, 6 May 2016. Further particulars of date, issue and author are unknown.

⁹⁴ Pullman, 'Science: A Very Short Introduction', p. xviii.

⁹⁵ Pullman, Personal communication, 6 May 2016.

‘They aren’t part of this universe at all; even the furthest stars are part of this universe, but the lights show us a different universe entirely. Not further away, but interpenetrating with this one. Here, on this deck, millions of other universes exist, unaware of one another... [...] I have just brushed ten million other worlds, and they knew nothing of it. We are as close as a heartbeat, but we can never touch or see or hear these other worlds except in the Northern Lights.’⁹⁶

Although Pullman could not have used Deutsch’s *The Fabric of Reality*, an interesting concept is explained in this book which also appears in Pullman’s trilogy. The fact that the double-slit experiment works when firing one photon at a time is explained by Deutsch as being caused by interference with particles from other universes.⁹⁷ This interference reminds one of the way in which the city of Cittàgazze can be seen through the Northern Lights.

A much older children’s book makes use of parallel worlds in a similar way, yet without referring to quantum physics. Tonke Dragt’s *De torens van februari* (1973, untranslated) tells the story of a fourteen-year-old boy who accidentally enters a parallel world by speaking a magic word.⁹⁸ In that world, he meets a girl of the same age. He also meets a scientist, the first person to find the magic word, who has established a scientific theory to explain these worlds: the two worlds exist on separate ‘time circles’ that only overlap between February and April.⁹⁹ This theory has no basis in real science. Because Pullman makes use of quantum physics, his readers recognize that his arguments against harmful scientific institutionalization apply not just in the fantasy world inside the novels, but also in their own world.

⁹⁶ Pullman, *Northern Lights*, 187.

⁹⁷ Deutsch, *The Fabric of Reality*, 46. This concept is also used in Michael Crichton’s *Timeline* to facilitate time travel, although the explanation of time travel in this work does not actually agree with the many-worlds theorem.

⁹⁸ Tonke Dragt, *De torens van februari (The Towers of February)* (1973; repr., Amsterdam: Leopold, 2014).

⁹⁹ Dragt, 103. Whereas L’Engle’s ‘time circles’ imply travel from one period in history to another, Dragt’s imply travel from one parallel world to another.

Gribbin and Gribbin explain that the subtle knife is a method to cut across dimensions.¹⁰⁰ This use of the many-worlds interpretation of quantum physics gives Pullman a rational, believable basis for the story and allows him not to demand a full suspension of disbelief. After all, if the story from Lyra's world merges apparently seamlessly into the science of Will's – the reader's – world, then the reader can speculate about how much of the arguments regarding morality and democracy could apply to their world.

Pullman uses the many-worlds interpretation to constrain the storyline temporally. In all parallel worlds, time passes at the same pace; since the subtle knife can only move from one world to the same time and place in another, it is impossible to travel through time by means of the subtle knife.¹⁰¹ In many fantasy stories, travel to another world implies time travel in some way: in *The Lion, the Witch and the Wardrobe*, the children spend half a lifetime in Narnia, but when they come back to England, the Second World War is still being fought. In L'Engle's *Time Quintet*, spacetime is manipulated through tessering: it can be folded, bent, and travelled through. The many-worlds interpretation allows Pullman to set parts of the story in separate worlds while maintaining the realistic necessities of the journey. The journey through the underworld cannot be made less long and gruelling simply by using the subtle knife. This use of the interpretation also constrains his story to a single timeline, which is helpful to the reader especially in *The Amber Spyglass*, in which so many parallel worlds are being

¹⁰⁰ Gribbin and Gribbin, *The Science of Philip Pullman's His Dark Materials*, 96.

¹⁰¹ In the short story 'The Collectors', it is suggested that time travel is possible, and that Mrs Coulter has travelled through time. No explanation is given. Philip Pullman, 'The Collectors: A His Dark Materials Story', Kindle (RHCP Digital, 2015), 24.

visited at the same time that the reader would struggle to follow the narrative if there were no chronological structure to fall back on.

In the first chapters of *Northern Lights*, it becomes clear that the idea of parallel worlds has up to this point been just as theoretical and hypothetical as the many-worlds interpretation of quantum physics is for our own. Called the Barnard-Stokes 'business', the idea was postulated by two 'renegade theologians who postulated the existence of numerous worlds [...] neither heaven nor hell, but material and sinful.'¹⁰² Barnard and Stokes were 'silenced' by the Church; however, as the Master of Jordan College explains, 'unfortunately for the Magisterium there seem to be sound mathematical arguments for this other-world theory. I have never followed them myself, but the Cassington Scholar tells me that they are sound.'¹⁰³ Cantrell argues that the Church persecutes the concept of possible worlds as a heresy because 'the multiplicity and difference of alternate worlds constitute a direct threat to the Church's control because the Magisterium cannot tolerate the mystery and ambiguity that such other spaces imply.'¹⁰⁴ Many Church scientists are afraid to admit that the interpretation is true even as they are using it:

'It's a process that actually makes use of the Barnard-Stokes heresy, the many-worlds idea...'
'Don't alarm yourself, doctor. Fra Pavel has told me that the child is in another world.'¹⁰⁵

¹⁰² Pullman, *Northern Lights*, 31. Italics in original.

¹⁰³ Pullman, 32.

¹⁰⁴ Sarah K. Cantrell, "Nothing Like Pretend": Difference, Disorder, and Dystopia in The Multiple World Spaces of Philip Pullman's *His Dark Materials*, *Children's Literature in Education* 41, no. 4 (3 August 2010): 302–22, <https://doi.org/10.1007/s10583-010-9112-1>, p. 308.

¹⁰⁵ Pullman, *The Amber Spyglass*, 334.

In *The Amber Spyglass*, it is revealed that the person who first came up with string theory suffered a similar fate, although the theory is not named: Mrs Coulter refers to 'a certain abominable heresy' in which a scientist 'had suggested that there were more spatial dimensions than the three familiar ones; that on a very small scale, there were up to seven or eight other dimensions'.¹⁰⁶ The status of both theories in Lyra's world reflects the position they hold to this day: the theory is mathematically sound, entirely unproven, and very attractive as a fictional trope.

Anne-Marie Bird writes that none of the parallel worlds in the trilogy are hierarchically superior,¹⁰⁷ but one world in the story is in fact markedly different from the others, both in scientific and in religious terms: the world of the dead. The connection between science and religion is lost at the point where Pullman introduces this world: the world of the dead, a religious concept, is not a parallel world that follows the many-worlds interpretation, since it is the world where the dead from all parallel worlds come together. The afterworld is given a special status because of the constraints of the internal logic of the story.

Pullman's afterlife is 'hell' as it was envisioned in pre- and early medieval times: 'quite simply and neutrally, the realm of the dead, that is of all the dead'.¹⁰⁸ Will does not cut a hole that leads straight into the world of the dead: he and Lyra enter a world that is similar to theirs, in which they encounter bodies of people who have recently died. Will has to cut a second hole from that world in order to get to the world of the dead, and this one is different from all the other passages that can be cut between

¹⁰⁶ Pullman, 396.

¹⁰⁷ Bird, "Without Contraries Is No Progression", 113.

¹⁰⁸ Rachel Falconer, *Hell in Contemporary Literature: Western Descent Narratives since 1945* (Edinburgh: Edinburgh University Press, 2004), 18.

worlds: 'He felt in the air with the knife-point. And at once he was aware of a new kind of sensation. [...] Just as the air had resisted the knife, so something in this opening resisted their going through.'¹⁰⁹ They come out in a world which looks exactly like the one they had just left, but in this one, the dead man is awake and talking to Will and Lyra; they follow him as he is irresistibly drawn to the land of the dead. This necessity for Will to create two holes with the knife is the first indication that the land of the dead in *His Dark Materials* is not simply another parallel world. It would not be possible for this world to be a regular parallel world according to the internal logic of the trilogy. There are only two ways to directly travel between worlds, through use of the subtle knife or through the release of an immense amount of energy, and both cause damage to the fabric of the world, making Dust disappear and Spectres spread. At the end of the trilogy, Will and Lyra learn that all these windows must be closed. The only window that is allowed to remain is the one that leads from the land of the dead to the world of the mulefa, in order to give the dead a way out, a way to turn into Dust. The dead, then, do not make such windows to get into the underworld: that would cause immense damage to the fabric of the universe.

The land of the dead is marked out as an unusual world: quantum physics behaves differently here. The existence of this underworld violates the many-worlds interpretation, and is the only world in this trilogy that does so. Whereas all parallel worlds are created by splitting off from each other, Pullman's underworld seems to be a single place that collects people from all other worlds. If the underworld were a regular parallel world, there would instead be innumerable underworlds.

¹⁰⁹ Pullman, *The Amber Spyglass*, 244–45.

The lodestone resonator does not work in this world: it seems to have become disentangled.¹¹⁰ The attempt in the underworld is the last time the two Gallivespians use the resonator before their death, which leaves the question open whether they would have been able to operate it again after their return to an ordinary universe. This return from the land of the dead is much easier than the descent, in keeping with Falconer's claim that 'the surprising facility of the return is [...] a marked feature of katabatic narratives.'¹¹¹ This time, only a single window needs to be cut to get out into the world of the mulefa.

Pullman does maintain one important scientific element in his depiction of the land of the dead which is not normally present in katabatic narratives: time's arrow. Time passes at the same pace in the land of the dead as in all other worlds: those who died thousands of years ago have indeed spent all that time in this land. In many other hell narratives, as Falconer points out, hell is presented as timeless, 'an extra-temporal absolute', a place in which time does not exist because everything happens simultaneously.¹¹² Following the many-worlds interpretation, Pullman keeps linear time intact in order to make sure that time has passed in the other worlds while Lyra and Will are down in the land of the dead.

The inclusion of concepts from quantum physics as plot devices has several effects on the narrative. First of all, it strengthens the connection between the book and the context in which it is read. The reader can look up the reference to Everett, and possibly not understand a word of it, but know that the idea behind it is not simply an

¹¹⁰ Pullman, 302.

¹¹¹ Falconer, *Hell in Contemporary Literature*, 167.

¹¹² Falconer, 50.

invention by Pullman. Like L'Engle, therefore, Pullman makes his creative universe more believable through using science. The epigraph of Chapter 21 of *The Amber Spyglass* is a citation by Byron that reflects this view: 'I hate things all fiction... There should always be some foundation of fact'.¹¹³ Also, by including science and religion as equally important elements in his work, he is able to show that one discipline is not inherently better than another, but that both should be regarded with caution as the people who control either discipline can use it to nefarious ends.

Pullman might be expected to oppose science and religion in his decidedly anti-Church trilogy, favouring science over religion as a whole, yet it is not the case that one is unconditionally good and the other is evil. In both worlds, the two are strongly intertwined. Mrs Coulter is a scientist who has the support of the church to pursue her line of research through the Oblation Board, and physics is known as 'experimental theology'; its experiments are done in the Chapel of Jordan College, for which it is equipped with 'philosophical apparatus'.¹¹⁴ Whereas Mrs Coulter uses science in the service of religion to undoubtedly evil ends, as she clinically observes the experimental process that leaves children worse than dead, Lord Asriel uses science to undermine the church, but is also willing to kill a child to accomplish his next step towards overthrowing the Authority – although Roger dies in an accident, and not through the murderous apparatus Lord Asriel had set up. Meanwhile, in Will's world, before dedicating herself to physics, Dr Malone had taken her vows as a nun. Both her scientific attitude and her previous history are essential to helping Lyra and Will accomplish the second Fall.

¹¹³ Pullman, *The Amber Spyglass*, 277.

¹¹⁴ Pullman, *Northern Lights*, 35.

Mary's role concerns Pullman's message about science and religion, and the role of individual freedom and debate in both.

Pullman presents an ambivalent view of science, countering the stereotypical 'ivory tower' idea that science is neutral, and is not, nor should be, politically involved. The subtle knife is one example, as Markman reminds us: it 'stands as a warning of the unintentional negative consequences of technology,' but it is 'not inherently evil,'¹¹⁵ it is a tool. The scientist as distanced from the rest of society is a common trope in fiction, especially where 'mad' scientists are involved: villains have all the time and money in the world to work on their creations, either on their own or aided by unintelligent minions, but unhindered by external interference.¹¹⁶ In *His Dark Materials*, however, the evil scientists are part of an institution. Dr Malone and Mrs Coulter are parallel figures in their ambivalent motherly relation to Will and Lyra respectively, and in their status as theoretical physicists. However, whereas Mrs Coulter is presented as an evil scientist especially in the first two books, heedlessly sacrificing destitute children to further her knowledge, Dr Malone is the one who eventually unravels the mystery of Dust, through collaboration with the mulefa and through experimentation on objects rather than on people, in a world in which she is the only human. Will's father John Parry is an equally morally sound scientist. Although he starts out as an experienced explorer helping out on an expedition, rather than as a formal scientist, after getting lost in a snowstorm and ending up in Lyra's world, he makes a name for himself as a scientist at its German Academy under the name Stanislaus Grumman. He then leaves Germany

¹¹⁵ Markman, 'Science, Technology and the Danger of Dæmons', p. 67.

¹¹⁶ Roslynn D. Haynes, *From Faust to Strangelove: Representations of the Scientist in Western Literature* (Baltimore: Johns Hopkins University Press, 1994), 94.

to become a shaman, and in that position invents the medicine that will save Will's life. Both characters choose to disconnect themselves from institutions, whereas Mrs Coulter and Lord Asriel both rely on formal connections to the Church and the university.

Pullman shows how science, like religion, can suffer from institutionalization, and how a nondemocratic approach to both can stifle the very principles on which the discipline was founded. Falconer points out that Pullman is offering 'a moral education' to his readers: he shows which kinds of behaviour are commendable, and which are not, and shows the influence individuals can have on the world based on their moral choices.¹¹⁷ Sound morals are essential in both science and religion. These moral values are more easily displayed in individuals acting alone than in institutionalized groups, which is another reason to show these scientists acting alone. The individual scientist as a moral example is a motif as old as science fiction: Mary Shelley's *Frankenstein* is one of the earliest negative examples, but Sleight points out that the nineteenth century also introduced the first exemplary, heroic scientists: she gives Charles Kingsley's Tom Turnall in *Two Years Ago* as an example.¹¹⁸

Pullman also makes a claim about the necessity for dissemination of, and access to, scientific knowledge, and public communication of science, by presenting a world without these elements in Lyra's Oxford. Markman points out that there are no public lectures in Oxford: Lord Asriel's presentation is held in a special room in college in which no women are allowed. This segregation of knowledge gives the Church free rein over their experiments with children: 'Because the Church was the only institution that

¹¹⁷ Falconer, *The Crossover Novel*, 75; Cantrell, "Nothing Like Pretend", 307.

¹¹⁸ Sleight, *Literature and Science*, 138. Notably, Sleight points out that the morality of *Frankenstein* is not straightforward; however, *Frankenstein* himself can by no means be interpreted as a morally sound character.

knew about this branch of science, they were able to decide for themselves that this research could be carried out without regard to the dangers it posed for the people who were the subjects of the study.’¹¹⁹ Lyra has never heard about Dust before in her haphazard education, until she secretly witnesses Lord Asriel’s presentation. Similarly, whereas her gender does not seem to be a hindrance in Dr Malone’s career, the precarious position of women scholars in Lyra’s Oxford is also frequently emphasized, a position which Lyra, growing up at an all-male college, has internalized:

The word *female* only suggested female Scholars to Lyra, and she involuntarily made a face. To be exiled from the grandeur of Jordan, the splendour and fame of its scholarship, to a dingy brick-built boarding house at the northern end of Oxford, with dowdy female Scholars who smelt of cabbage and mothballs like these two at dinner!¹²⁰

Access to knowledge must be democratic and universal in both science and religion, the angel Xaphania explains to Mary at the end of *The Amber Spyglass*: ‘She said that all the history of human life has been a struggle between wisdom and stupidity. She and the rebel angels, the followers of wisdom, have always tried to open minds; the Authority and his churches have always tried to keep them closed.’¹²¹ Lyra subsequently sees Oxford in a new light: ‘[Lyra] found that her memory was at fault: for this Dame Hannah was much cleverer, and more interesting, and kindlier by far than the dim and frumpy person she remembered.’¹²² Having resisted being schooled all her life, Lyra realises the value of knowledge and enrolls in Dame Hannah’s boarding school as preparation

¹¹⁹ Markman, ‘Science, Technology and the Danger of Dæmons’, p. 66.

¹²⁰ Pullman, *Northern Lights*, 71.

¹²¹ Pullman, *The Amber Spyglass*, 482.

¹²² Pullman, 515.

for a life as a scholar. As O'Sullivan puts it, '*His Dark Materials* is a children's text that narrates the desirability of ending childhood innocence.'¹²³

One aspect of scientific research, one which a young reader is unlikely to have previously encountered, is experienced similarly in both worlds: the struggle for funding to investigate Dust. Pullman uses funding as a means to show the reader the politics that go on inside the university, as well as the ways in which university policies can be influenced by outside politics. Notably, there seem to be only two sources of political power: the university and the Church – there is no separate state authority in this world. Lord Asriel presents his latest findings on Dust at Jordan College in hope of obtaining funding for a new expedition to the North Pole, something the Master of the college is so eager to prevent that he intends to poison Lord Asriel. Similarly, the reader first meets Mary Malone when she is on the brink of giving up any hope for funding, until on that same day she discovers dark matter is conscious.¹²⁴ Now Mary Malone must learn how to communicate with Dust that very night, because she only has limited time left. Lyra fully understands the funding issue, and advises Dr Malone that being able to communicate with Dust may convince the funding committee.¹²⁵ In both these instances, the struggle for funding provides a major motivation for plot development. Even the funding body of the Arctic expedition of John Parry, Will's father, is mentioned: 'the Institute of Archaeology at Oxford University'.¹²⁶ Within that expedition, there is one other person who has heard of the portal to another world, and again it is

¹²³ Keith O'Sullivan, "'Without Contraries Is No Progression": Romantic Constructions of Childhood and Philip Pullman's *His Dark Materials*', in *Philip Pullman: His Dark Materials*, ed. Catherine Butler and Tommy Halsdorf (Basingstoke: Palgrave Macmillan, 2014), 113–26, p. 116.

¹²⁴ Pullman, *Northern Lights*, 3–28; Pullman, *The Subtle Knife*, 86.

¹²⁵ Pullman, *The Subtle Knife*, 97.

¹²⁶ Pullman, 81.

his funding that gives away this physicist's real motives: 'although he is a bona fide academic his funding actually comes from the Ministry of Defence'.¹²⁷

This funding issue implies that scientific conflicts are rife in both worlds. On the one hand, as Waller points out, Pullman shows the reader that debate is essential in the process of scientific discovery, as 'vehement disagreements over scientific knowledge are hardly uncommon in our own world and to a degree they indicate a healthy environment of scholarly exchange.'¹²⁸ On the other hand, he shows how these conflicts can arise from rivalry and greed, and can hinder further scientific development. The attempt of the Master of Jordan College to poison Lord Asriel is an act that combines political, religious and scientific conflict, but the most striking example of a science war comes when Lyra is thrown into the prison of Iofur Raknison. 'A grey-bearded man chained to the wall' introduces himself as 'Jotham Santelia [...] the Regius Professor of Cosmology at the University of Gloucester.' When Lyra reveals that she is from Jordan College, the man flares up: 'Is that scoundrel Trelawney still there? Eh? [...] They should have forced his resignation long ago. Duplicitous plagiarist! Coxcomb! [...] Has he published his paper on gamma-ray photons yet? [...] Scoundrel! Thief! Blackguard! Rogue!'¹²⁹ Science conflict is introduced in a comedic fashion, in order to ridicule how deeply ingrained personal conflicts can be in scientific practice: Santelia's resentment against his colleague goes so deep that it haunts him even when he is incarcerated by armoured bears. Lyra uses this resentment to wheedle important information from

¹²⁷ Pullman, 113.

¹²⁸ Waller, 'The Pursuit of Knowledge', 63.

¹²⁹ Pullman, *Northern Lights*, 326–27.

him with which she can outwit Iofur Raknison and install Iorek Byrnison as the rightful king of the *panserbjørne*.

Naomi Wood claims that Pullman omits ‘references to oppressive secular institutions’,¹³⁰ in favour of attacking religious ones, yet it is through this depiction of conflict that the oppressive control over science in our world is shown in the trilogy. Mary is forced to create the programme that will allow her to talk to the Shadow-particles in absolute secrecy, as she knows her colleague Oliver Payne will betray her and accept Sir Charles’s funding:

‘It’s simple. You promise to do as he says, you get the funding, I leave, you take over as Director. It’s not hard to understand. You’d have a bigger budget. Lots of nice new machines. Half a dozen more Ph.D.s under you. Good idea. You do it, Oliver. You go ahead. But that’s it for me, I’m off. It stinks.’¹³¹

She ends up destroying the machine before she leaves Oxford, permanently hindering the work of her successor.

The scientific enterprise in both worlds is thus dependent on external parties, who are more powerful because they possess the financial means to determine which kinds of scholarship are worth pursuing. In Lyra’s Oxford, the Church can turn scientific research, as King notes, into ‘an instrument of institutional authority, complicit in the disciplining of human experience: what begins as free inquiry into meaning can become altered to a mechanism for reinforcing existing power relations’.¹³² It is suggested that even though science seems to have more freedom in our world than in

¹³⁰ Naomi Wood, ‘The Controversialist: Philip Pullman’s Secular Humanism and Responses to *His Dark Materials*’, in *Philip Pullman: His Dark Materials*, ed. Catherine Butler and Tommy Halsdorf (Basingstoke: Palgrave Macmillan, 2014), 76–95, p. 86.

¹³¹ Pullman, *The Subtle Knife*, 245.

¹³² King, ‘Exegesis, Allegory, and Reading *The Golden Compass*’, p. 120.

Lyra's, scientific development can be largely determined by who funds it: a lengthy passage in *The Subtle Knife* shows that even an apparently transparent process such as a peer-reviewed grant application is in fact very much based on knowing and convincing the right people. Sir Charles Latrom presents himself as being in precisely such a position, so that he would be able to fund the research in Mary's department, perhaps with additional funding from the defence department – but also, that this research would be conducted entirely on his terms. Mary's colleague Oliver Payne is convinced, but Mary herself is not: "It wasn't an offer," she said hotly, "it was an ultimatum."¹³³ Pullman thus shows how essential human agency is to science. Whether to accept defence funding, or otherwise morally dubious funding, or not, is a dilemma faced by researchers at all levels today, especially in the sciences. In *His Dark Materials*, science, religion and politics are thus made to rely on and influence each other in equal measure.

Conclusion

Philip Pullman's *His Dark Materials* and Madeleine L'Engle's *Time Quintet* are two series of children's books which combine quantum physics and religion in a fantastical setting to convey their respective messages about science and religion. The main argument that the authors make applies to both fields. In the two series, science is authoritative and the author has gone to great lengths to provide scientific accuracy. The science lends an authority to the narrative, grounding the fantastical events. Both authors make an argument that applies to both science and religion: in Pullman's case, about

¹³³ Pullman, *The Subtle Knife*, 243.

democracy; in L'Engle's case, about adaptability. By combining this scientific background with a story in which religion is central, they show that neither is the ultimate authority, and that the authors' perspective applies to both.

The perspectives both authors advocate, however, differ drastically: whereas L'Engle integrates science with religion, expressing the need for collaboration and a connection between the two, Pullman expresses a strong rejection of the religious status quo. In the Time Quintet, science provides the background setting to L'Engle's story, but the integration of religious ideas creates its resolution. L'Engle compares science and religion to make a claim for open-endedness and openness to change. She shows that science and religion address similar topics, that they are not mutually exclusive, and that there is a place for religion amongst the most modern scientific developments.

In *His Dark Materials*, Pullman argues for institutional reform rather than collaboration, in an argument that applies to both religion and science: in his trilogy, there has been a struggle between knowledge and ignorance in both fields, and an attempt to keep people ignorant. Pullman proposes a democratic view of both religion and science: the Republic of Heaven must replace the Kingdom of Heaven; science must be open-minded and accessible, since both science and religion can be dangerous in despotic hands. By making not only the concept of scientific enquiry but also real scientific concepts part of his story, Pullman strengthens his argument regarding scientific practice. Pullman's case for democracy in science, religion, and all other forms of knowledge is made more strongly through this connection to potential real-world applications. A discussion of Pullman's approach to religion in *His Dark Materials* is therefore incomplete if his approach to science is not taken into account.

Both series, by including both quantum physics and religion, create an up-to-date discussion of religion that can be continued in the twenty-first century. Even L'Engle's early works present scientific questions which are still wrestled with, implying that the religious questions she asks alongside them are still valid. L'Engle and Pullman show their readers how their ideal approach to science and religion can be achieved, but do so only at an individual level: they are both opposed to excessive institutionalization. For L'Engle, science and religion are to be approached in a more personal manner. For Pullman, both, and all other forms of knowledge, should be organized democratically; open communication is an essential part of this process. Both authors give concrete examples of situations in modern-day science and religion which they want to open up to their views. As a scientific field that is often connected to religion, as well as a field whose metaphysical implications are narratologically attractive, quantum physics helps steer and shape their plots. Including quantum physics has made it possible for both authors to address centuries-old questions about morality and knowledge, and show that these questions are still valid to this day.

If questions like these can be explored in children's fiction, how could fiction for adults make use of quantum physics? Fictional works written for adult readers tend to have more room for experimentation with narrative form. The next chapter will investigate the use of various different interpretations of quantum physics and their influence on both the form and content of adult fiction.

Chapter Six: Quantum Mechanics as a Narrative Trope in Fiction

Introduction

Every action described in a narrative entails a choice on the part of the author, leaving the ghosts of countless potential other stories lingering on every page. What if a woman had washed up on Robinson Crusoe's island; what if Charlotte Brontë had offered a more sympathetic version of Bertha Rochester's history in *Jane Eyre*; what if Jane Austen had given a supernatural reason for the presence of a military regiment near the Bennet house? Such speculation has led to re-interpretations by other authors – *Foe*; *Wide Sargasso Sea*; *Pride and Prejudice and Zombies* – but apart from the occasional novel with an alternate ending, such as *The French Lieutenant's Woman*, other possible routes within a text are retrievable only through speculation.¹ In his 1941 short story 'The Garden of Forking Paths,' Jorge Luis Borges introduced a writer who did attempt to write all possible versions of a narrative.² In this story, *The Garden of Forking Paths* is a work of literature written by the Chinese author Ts'ui Pen, the great-grandfather of the first-person narrator, Hsi P'eng. The work, which took Ts'ui Pen thirteen years to write, had been disregarded by the generations after him as a 'contradictory jumble of irresolute drafts.'³ However, the British sinologist Stephen Albert discovered that Ts'ui Pen had instead written a unique work of literature. He explains to the narrator:

'In all fictions, each time a man meets diverse alternatives, he chooses one and eliminates the others; in the work of the virtually impossible-to-disentangle

¹ J. M. Coetzee, *Foe* (New York: Penguin Books, 1987); Jean Rhys, *Wide Sargasso Sea* (London: Deutsch, 1966); Seth Grahame-Smith and Jane Austen, *Pride and Prejudice and Zombies* (Philadelphia: Quirk Books, 2009); John Fowles, *The French Lieutenant's Woman* (London: Cape, 1969).

² Jorge Luis Borges, 'The Garden of Forking Paths,' in *Collected Fictions*, trans. Andrew Hurley (London: Allen Lane, 1998), 119–28.

³ Borges, 124.

Ts'ui Pen, the character chooses – simultaneously – all of them. *He creates*, thereby, 'several futures,' several *times*, which themselves proliferate and fork. [...] In Ts'ui Pen's novel, *all* the outcomes in fact occur; each is the starting point for further bifurcations.⁴

The work describes all possible outcomes of each choice the narrator makes, thus presenting a universe that does not consist of a single timeline. Albert explains that Ts'ui Pen had a unique conception of the fabric of the universe:

'The explanation is obvious: *The Garden of Forking Paths* is an incomplete, but not false, image of the universe as conceived by Ts'ui Pen. Unlike Newton and Schopenhauer, your ancestor did not believe in a uniform and absolute time; he believed in an infinite series of times, a growing, dizzying web of divergent, convergent, and parallel times. That fabric of times that approach one another, fork, are snapped off, or are simply unknown for centuries, contains *all* possibilities.'⁵

With this story, Borges anticipated Hugh Everett's many-worlds interpretation so closely that an extract of the story was used as the epigraph of Bryce DeWitt's 1973 edited collection on this interpretation, which for the first time brought Everett's work to serious consideration by physicists.⁶

Borges's story, written more than a decade before Everett wrote his paper, exemplifies the way in which scientific theorization may touch upon ideas that storytellers have been exploring long before a scientific grounding was found for these ideas. As Marie-Laure Ryan has noted, however, the possibilities for exploring the many-worlds interpretation in fiction are limited.⁷ It is impossible to write a fictional narrative that follows the concept of the many-worlds interpretation to the fullest extent. 'The Garden of Forking Paths' avoids this problem by merely *describing* the book *The*

⁴ Borges, 125.

⁵ Borges, 127.

⁶ Bryce S. DeWitt and Neill Graham, eds., *The Many-Worlds Interpretation of Quantum Mechanics: A Fundamental Exposition* (Princeton, NJ: Princeton University Press, 1973), vi.

⁷ Ryan, 'From Parallel Universes to Possible Worlds'.

Garden of Forking Paths, rather than attempting to show the reader what such a book would look like when written:

The problem with Ts'ui Pen's novel is that it cannot be written. This is why Borges embeds its description within a perfectly linear short story that projects a classical ontology. It cannot be written, because a narrative must limit itself to a subset of all possibilities and because its branches must be presented sequentially rather than simultaneously.⁸

Such a narrative would be inherently nonlinear, whereas Albert claims that 'I have re-established, or believe I've re-established, its fundamental order.'⁹ There cannot be a fundamental order for a branching narrative. The narrative is also, as Stephen Albert mentions in the story, necessarily 'incomplete', because an author would never have the time to render every single branch of the multiverse into writing.

Although Borges does not follow the implications of a branching universe to the letter, his thought experiment, which we now know to have a possible basis in physical reality, leads to a fascinating story. Quantum physics has the potential to provide both new material for narratives, and new ways to apply existing narrative tropes, leading to works that are sometimes classified as 'quantum fiction'; however, this is a problematic term, as I will explain below.¹⁰ Authors in recent decades have used quantum physics to provide a scientific underpinning for events which a century ago would have sounded fantastical: unsurprisingly, science fiction was the first genre to embrace the concepts of quantum physics explicitly. The Copenhagen interpretation, presenting a

⁸ Ryan, 653–54.

⁹ Borges, 'The Garden of Forking Paths', 127.

¹⁰ E.g. in Sonia Front, *Shapes of Time in British Twenty-First Century Quantum Fiction* (Newcastle: Cambridge Scholars Publishing, 2015); Sean Kinch, 'Quantum Mechanics as Critical Model: Reading Nicholas Mosley's *Hopeful Monsters*', *Critique: Studies in Contemporary Fiction* 47, no. 3 (1 March 2006): 289–308, <https://doi.org/10.3200/CRIT.47.3.289-308>; Serpil Opperman, 'Quantum Physics and Literature: How They Meet the Universe Halfway', *Anglia* 133, no. 1 (1 March 2015): 87–104, <https://doi.org/10.1515/ang-2015-0007>.

single timeline, offers the possibility of travelling back in time to cause a different collapse of the wave function and thus change the past and future. The conscious collapse interpretation, which posits that only a conscious being such as a human could cause the collapse of the wave function, hinted at instant communication and telepathy. The many-worlds interpretation has been linked with ideas of alternative histories and the possibility of time travel. David Deutsch even goes as far as claiming that 'for time travel to be physically possible it is necessary for there to be a multiverse' in order to avoid creating paradoxes.¹¹ However, this interpretation does *not* allow the possibility of changing one's own past, as travelling to one's past and changing it causes branching, which leads to a new world separate from the one the traveller has come from.

Various obstacles arise when one attempts to incorporate quantum physics in a narrative. The author cannot assume that the reader knows anything about quantum physics. Many of the authors who write about quantum physics make use of the generic conventions of science fiction, in which asking readers to absorb large amounts of new information is common practice, and many of these authors have a background in science. Yet even when, or perhaps especially when, both reader and writer have a university-level understanding of quantum theory, it becomes clear that there is a limit to the extent to which one can build a narrative upon the theory. The author must extrapolate from currently available scientific knowledge. They must decide which interpretation of quantum physics to employ for the purposes of the narrative: does the observer influence the collapse of the wavefunction? Does the wavefunction collapse at all, or does the universe branch? Choosing which interpretation of quantum theory to

¹¹ Deutsch, *The Fabric of Reality*, 310.

follow can lead to very different possibilities for narrative form and content. Making this choice also means extrapolating from the present situation in which there is no common agreement regarding the various interpretations and their validity, as there is no method yet to determine which is valid.

In the early twentieth century, several literary works anticipated scientific developments, as can be seen in Jorge Luis Borges's and Andre Norton's use of many-worlds-like multiverse structures in 'The Garden of Forking Paths' and *The Crossroads of Time* (1956) respectively. Although it is beyond the scope of this research to determine whether or not these fictions in any way influenced scientific developments, they do show both that existing narrative tropes could help in popularizing and explaining quantum physics, and that this science could potentially easily be incorporated into fiction by connecting to these tropes. Interpretation choice itself can be made part of the narrative, as Gregory Benford has done in *Timescape* (1980) and Iain Pears in *Arcadia* (2015), bringing an exciting scientific discovery plot into the narrative.¹²

Quantum physics permeated fiction beyond SF from the 1990s onwards, after a large growth in popular science publishing during the 1970s-1990s.¹³ These ideas influenced narratives in many different ways, ranging from simple references to make the story sound more scientifically informed, to an entirely original narrative that relies heavily on quantum physics for both its form and content. This chapter investigates works of fiction that apply quantum physics to the narrative explicitly and obviously, so that the reader will be aware of the presence of quantum physics. The fact that a

¹² Gregory Benford, *Timescape*, Ebook (New York: Simon and Schuster, 1980); Iain Pears, *Arcadia* (London: Faber & Faber, 2015).

¹³ Leane, *Reading Popular Physics*, 1.

novel is written in an age in which knowledge of quantum physics is widespread, a criterion used by several 'quantum fiction' critics discussed below, is not sufficient in itself: these critics have a tendency to assert causal relationships between the science and the fiction which are difficult to demonstrate. If a work is written after a scientific discovery is made, the author will not necessarily have been aware of the discovery, or have intended to use it; the chronological plausibility of influence is seductive but insufficient evidence.

Quantum physics could potentially influence narrative form to a much fuller extent than existing fiction has attempted. Digital fiction, a form developed over the past forty years, could facilitate interactive narratives grounded in quantum physics. Technology that allows for branching narratives, for instance through allowing the reader to choose between several options to select the next passage to read, as Iain Pears's app version of *Arcadia* does, brings us much closer to the possibility of creating a story that approximates *The Garden of Forking Paths*. Interactive narratives, and the (limited) freedom of choice a reader has, allow for the creation of branching worlds in the narrative's very structure. *Arcadia*, however, is limited in its usage of interactive technology, and I have so far not identified any other works that explore the possibilities of quantum physics in interactive fiction. The most common usage of quantum physics in fiction is still rather limited: as a post-hoc explanation, a passing reference which suggests that something works because of quantum physics. The reader is supposed to suspend disbelief, because the narrative requires this leap to get to the next step in the storyline. A narrative might follow the many-worlds interpretation of quantum physics by starting off from a single origin, from which the reader would be able to choose where to go next at any given moment; the story would have a linear cause-and-effect

structure, but the reader would be able to go back to a previous point and explore a different branch from there. A many-worlds storyline would have a range of different possible endings; however, unlike other open-ended works of interactive fiction such as Michael Joyce's *afternoon, a story* (1987),¹⁴ it would not be possible to go round in circles by choosing the same sequence of hyperlinks again and again.

Quantum physics, then, is able to open up new narratives by indicating that things previously thought entirely impossible are now being investigated as potentially possible, while still offering structural rules that the narrative should adhere to, thus maintaining order and reader comprehension. I will inquire how quantum physics has influenced fiction and created two kinds of estrangement at the same time. It has made the familiar strange again, by providing new ways to apply existing story tropes, and it has made the strange comprehensible, by introducing complicated scientific phenomena through a captivating fictional narrative. Fiction about quantum physics shapes the way in which the reader thinks about the topic: what they understand quantum physics to be, which concepts are associated with it, and what the potential implications of this branch of science could be for the future.

In the late 1980s, critics started noting the frequent appearance of quantum physics in science fiction. Patricia Warrick discusses the simultaneous appearance of quantum physics tropes in popular physics books, such as Capra's *The Tao of Physics* (1975) and Gribbin's *In Search of Schrödinger's Cat* (1984), and science fiction, by writers such as Gregory Benford (*Timescape*, 1980), Greg Bear ('Schrödinger's Plague,'

¹⁴ Michael Joyce, *afternoon, a story*, *Norton Anthology of Postmodern American Fiction, Special Web Edition*, 1987, <http://www.wwnorton.com/college/english/pmaf/hypertext/aft/index.html>.

1982), and Rudy Rucker (*The Sex Sphere*, 1983).¹⁵ Non-physicists in these decades could therefore seek out books that would teach them about quantum physics, but those readers who didn't actively look for information on the topic were also more likely to encounter it, in fiction. As has been discussed in previous chapters, science fiction has no obligation to instruct or to present a scientifically accurate narrative, whereas popular science books tend to be didactic.¹⁶ Even so, several of the novels discussed below present infodumps on quantum physics that sometimes make entire pages of a science fiction novel look rather like a work of popular science.

Warrick discusses Philip K. Dick as an author whose works contain quantum physics. However, her argumentation regarding Dick shows some flaws. Warrick points out that Dick's works do not explicitly refer to quantum physics, but that he still makes use of concepts also found in this branch of science:

Dick's imaginary universes are often described as weird and bizarre, exactly the terms used by physicists in describing quantum reality. His greatest novels use multiple points of view, with each character seeing a different universe, thus expressing Dick's awareness that the observer participates in creating the universe where he lives.¹⁷

As I will explain further below, the necessity of observer participation is indeed part of one interpretation of quantum physics. However, Warrick's connection between Dick and quantum physics based on the terms 'weird' and 'bizarre' is much too tenuous. These two terms do not define, and are not limited to descriptions of, quantum reality;

¹⁵ Patricia Warrick, 'Quantum Reality in Recent Science Fiction', *Extrapolation* 28, no. 4 (Winter 1987): 297–309; Capra, *The Tao of Physics*; Gribbin, *In Search of Schrödinger's Cat*; Benford, *Timescape*; Greg Bear, 'Schrödinger's Plague', *Analog*, 29 March 1982, 62–69; Rudy Rucker, *The Sex Sphere* (New York: Ace, 1983).

¹⁶ This claim may sound obvious, but one counterexample would be Ben Miller, who in his popular science book *It's Not Rocket Science* explicitly states that 'The purpose of other books may be to educate you, or provoke you, or challenge you; the purpose of this one is simply to entertain you.' Miller, *It's Not Rocket Science*, 24.

¹⁷ Warrick, 'Quantum Reality in Recent Science Fiction', 305.

plenty of palaeontologists, for example, have called certain fossils weird and bizarre¹⁸ but that does not create a connection between these paradigm-shifting fossils and Philip K. Dick's literature. Since there is no overt evidence of a connection to quantum physics, Dick's works will not be discussed in this chapter.

During the so-called 'science wars' of the late 1990s, research that bridged the humanities and the sciences was met with strong criticism from the science side, and quantum physics in particular was singled out as a source of contention.¹⁹ By this decade, both authors and literary critics had started to make use of quantum physics to such an extent that it drew the attention of physicists, who did not always agree with the variously drawn connections between postmodernism and quantum physics. Much has been written about the 'science wars', which started in 1996 when physicist Alan Sokal published the nonsense paper 'Transgressing the Boundaries: Towards a Transformative Hermeneutics of Quantum Gravity' in the humanities journal *Social Text*.²⁰ Sokal and Jean Bricmont followed this paper up with the book *Intellectual Impostures: Postmodern Philosophers' Abuse of Science*.²¹ Sokal and Bricmont identify four transgressions: 'holding forth at length on scientific theories about which one has, at best, an exceedingly hazy idea'; 'importing concepts from the natural sciences into the hu-

¹⁸ E.g. H.B. Whittington, 'The Enigmatic Animal *Opabinia Regalis*, Middle Cambrian, Burgess Shale, British Columbia', *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences* 271, no. 910 (1975): 1–43; Keynyn Brysse, 'From Weird Wonders to Stem Lineages: The Second Reclassification of the Burgess Shale Fauna', *Studies in History and Philosophy of Biological and Biomedical Sciences* 39, no. 3 (September 2008): 298–313, <https://doi.org/10.1016/j.shpsc.2008.06.004>.

¹⁹ Leane, *Reading Popular Physics*, 78; Daniel Cordle, *Postmodern postures: literature, science and the two cultures debate* (Aldershot: Ashgate, 1999); Willis, *Literature and Science*, 7–8.

²⁰ Alan Sokal, 'Transgressing the Boundaries: Toward a Transformative Hermeneutics of Quantum Gravity', *Social Text*, no. 46/47 (Spring-Summer 1996): 217–52.

²¹ Alan Sokal and Jean Bricmont, *Intellectual Impostures: Postmodern Philosophers' Abuse of Science* (London: Profile Books, 1998). In the US, the book is titled *Fashionable Nonsense*.

manities [...] without giving the slightest conceptual or empirical justification'; 'shamelessly throwing around technical terms in a context where they are completely irrelevant' and 'manipulating phrases that are, in fact, meaningless'.²² Although Sokal and Bricmont bring a rather blinkered perspective to their analysis, it is nonetheless clear that all four 'transgressions' can arise in literary criticism of fiction that works with quantum physics, a field Sokal singled out for this reason in the title of his paper.

Sokal and Bricmont do not discuss physics in fiction, apart from using Rebecca Goldstein's *Properties of Light* as a reference in the works cited list of the original sham paper; in *Intellectual Impostures*, they describe it as an 'enjoyable novel', emphasizing the idea that including a novel as a secondary source in this particular academic context is ridiculous – and that the editors of their paper had let them get away with it.²³ Goldstein's work is indeed a novel about quantum physics, in particular about hidden variable theory; I do not discuss the work here because I focus on works that make use of three other interpretations: Copenhagen, conscious collapse, and many-worlds.

The kinds of transgressions that *Intellectual Impostures* warns against are made in both the genesis and critical discussions of what has been termed 'quantum fiction'. Author Vanna Bonta (1958-2014) is usually credited with coining the term 'quantum fiction' in *Flight: A Quantum Fiction Novel* (1995).²⁴ Her novel is pseudoscientific, as I will discuss below, and the term continues to be applied to pseudoscientific fiction that pretends to ground itself in quantum physics. Furthermore, it is not unusual for works

²² Sokal and Bricmont, 4.

²³ Sokal and Bricmont, 243. Emphasis in original; Rebecca Goldstein, *Properties of Light: A Novel of Love, Betrayal, and Quantum Physics* (2000; repr., Boston: Houghton Mifflin, 2001).

²⁴ Vanna Bonta, *Flight: A Quantum Fiction Novel* (San Diego, CA: Meridian House, 1995).

to be designated 'quantum fiction' even when there is no conscious and/or visible attempt on the writer's part to engage with quantum physics. I would therefore argue that studies of quantum physics fiction struggle with a history of several decades of work that has looked at a very wide range of irrelevant fiction somehow labelled 'quantum', which I will show below to have no direct relation to quantum physics, or work that has, in the worst cases, angered physicists and turned them against such research.

Quantum Fiction

Limited scholarly attention has been paid to 'quantum fiction', and the interpretations of this term by these few critics are so wide-ranging that one can conclude that there is no consensus as to what it precisely entails. Most 'quantum fiction' criticism seems to limit itself to pointing out where authors made use of something that can be classified as quantum physics, rather than, as I do here, showing how the use of specific interpretations of quantum physics can shape the form and content of the narrative, and the reader's understanding of the science. The pointing-out approach can be seen for instance in the work of Sonia Front.²⁵

It is perhaps unfortunate that the term remains connected to Bonta's novel. Both the work's literary merits and its use of quantum physics are questionable. No major publications have reviewed *Flight*, and the one science fiction publication that discussed the novel dismissed it as 'pseudo-scientific babble'.²⁶ Unlike the works ex-

²⁵ Front, *Shapes of Time*.

²⁶ 'Review: Flight, by Vanna Bonta', Madhouse Manor: The Debra Doyle and James D. Macdonald Homepage, accessed 16 August 2016, http://www.sff.net/people/doylemacdonald/r_flight.htm.

plored further in this chapter, Bonta's work does not convey an understanding of specific concepts from quantum physics. Instead, the plot of *Flight* implies a mystical, pseudoscientific understanding of quantum physics. Science fiction author Mendle J. Orion has created a new heroine, Aira Flight, and begins to believe she is real, up to the point where he terminates his relationship with the journalist Sandra because he prefers Aira. At a science fiction conference, he suddenly finds an amnesiac woman in his bathroom. He calls her Aira, and she turns out to be the space-travelling heroine from Mendle's new novel. As Aira regains her memory and her powers, she comes to bring a message of peace and love to the world, her most important message being that sex is about the person instead of the body, and she convinces all of humanity to come out and sing in unison on 3 April 2000.

Bonta's connection between quantum physics and human consciousness is vaguely linked to the conscious collapse interpretation of quantum physics, although she doesn't mention this term in the novel. Her explanation of the term 'quantum fiction' in a 1997 interview shows more clearly that her understanding of quantum physics and the use of the word 'quantum' to describe her fiction is based on a mystical extrapolation of the conscious collapse interpretation, if it is based on any formal interpretation at all:

VB: Quantum fiction is any story that witnesses life and the human experience on a sub-atomic level. It involves quantum theory, bringing it forward as a possible explanation behind the concept of life imitating art, and art imitating life, in that all of us are – to some degree – the authors of our lives, in how we interact with reality. So, in the case of characters in quantum fiction, they bridge science, philosophy, and cognition, or the involvement of consciousness.²⁷

²⁷ Laurel van der Linde, 'An Interview With Author, Vanna Bonta Regarding Flight, A Quantum Fiction Novel', Gather, 23 January 2008, <https://web.archive.org/web/20131016205331/http://www.gather.com/viewArticle.action?articleId=281474977238495>.

The extrapolation is illegitimate; it is difficult to analyse this exposition in terms of actual quantum physics. To 'witness' life or human experience on a sub-atomic level would require fictional inventions that have nothing to do with quantum theory. There is certainly a form of philosophy and a discussion of consciousness involved in Bonta's 'quantum fiction', but it does not actually encompass any recognizable interpretation of the science as well.

The term 'quantum fiction' continues to be employed by critics, often with only a passing yet obligatory reference to Bonta. Sonia Front, for instance, in *Shapes of Time in British Twenty-first Century Quantum Fiction*, claims that

Quantum fiction [...] refers to 'a new literary genre' that appeared at the end of the twentieth century to reflect the experience of reality as described by quantum mechanics. However, although Bonta claims to have invented the genre, it came into being much earlier: some modernist novels have been interpreted from this critical standpoint.²⁸

Although Front does not explain which modernist novels have been interpreted through a quantum mechanical lens, it is indeed the case that before Bonta, other critics worked with a similar concept. Susan Strehle coined the term 'actualistic fiction' in *Fiction in the Quantum Universe* (1992); she derived it from Werner Heisenberg's distinction between the 'real' and the 'actual' and defines this genre as 'a literary version of the reality constituted by fundamentally new physical theories in the first half of the twentieth century.'²⁹ As Kinch points out, several of the most important interpretations

²⁸ Front, *Shapes of Time*, 29. See also my reference earlier in the thesis to Whitworth (2001), who pointed out that most of the major modernist works were written before the development of quantum theory in the 1920s.

²⁹ Susan Strehle, *Fiction in the Quantum Universe* (Chapel Hill: University of North Carolina Press, 1992), 7. Heisenberg distinguished 'real' from 'wirklich', translated as 'real' and 'actual' respectively. As Bitbol explains, 'being "real" in the sense which a thing of everyday life is, does not *only* mean being located in ordinary space, but also being "wirklich", or "actual", by opposition to "having no effect", "virtual" or

for fiction, including the many-worlds interpretation, do not fit within Strehle's model of actualistic fiction; her model is problematic insofar as it 'seems to presume that quantum mechanics has already been adequately interpreted and that fiction writers need merely find appropriate forms to express that interpretation.'³⁰ The simultaneous existence of multiple interpretations strongly influences the fiction discussed in this chapter, as authors select the interpretation that best fits their narrative purpose, without directly contradicting the scientific status quo in making such a choice.

Front's definition of 'quantum fiction' is rather too broad and imprecise to define the kinds of texts I work with here:

Contrary to science fiction, primarily defined by content, quantum fiction is mainly identified by the technique of writing, and anything can become its subject matter; the narrative can but does not have to be science-oriented. The narratives employ non-chronological plots and disrupted temporalities to render the characters' experience of quantum reality, such as parallel worldlines in the multiverse, synchronicity (mirroring quantum entanglement), the impossibility of (quantum) suicide, consciousness as an active participant in the creation of reality, holism, and so on.³¹

Non-chronological plots, synchronicity, and, as I will point out below, even parallel worldlines were present in literary plots – and especially in science fiction plots – before the development of quantum physics: it is unclear what criteria are used, other than publication date, to distinguish such works from quantum fiction.

Front's discussion of David Mitchell's *Cloud Atlas* as an example of quantum fiction, for instance, is debatable. She writes that 'The scaffolding of eternal recurrence is also employed in the novel to illustrate the notion of a quantum field, of the underlying

"potential".' Michel Bitbol, *Schrödinger's Philosophy of Quantum Mechanics* (Dordrecht: Kluwer Academic Publishers, 1996), 101.

³⁰ Kinch, 'Quantum Mechanics as Critical Model', 292.

³¹ Front, *Shapes of Time*, 29.

reality in which everything is connected.’³² Actually, there is no single ‘underlying reality’ in this *mise-en-abyme* narrative: for instance, the section titled ‘Half-Lives: The First Luisa Rey Mystery’ shows up as a fictional story in the next section.³³ The notion of a quantum field is also not ‘illustrated’ in the novel: although one protagonist is a physicist and references to other physics theories are made, quantum field theory is not referred to at all in this novel. Front describes how *Cloud Atlas* is linked to Poincaré’s recurrence theorem, which states that some systems will after a certain length of time revert to their initial state. The recurrence theorem therefore applies to systems governed by quantum field theory, but also to any other finite closed physical system: the inclusion of this theorem, even if explicit in the novel, would not illustrate the notion of quantum field theory. The theorem, however, is not referred to. Although Mitchell has written that ‘On my bleaker days, humanity’s future looks disturbingly like its past’,³⁴ nowhere in the book does he refer to the idea of reversion explicitly, and the similarity to Poincaré’s theorem is implicit and vague enough to be called coincidental. In this chapter, I will avoid the charge of projecting quantum physics on a text, at the risk of missing out on works that are influenced by quantum physics although they do not mention it explicitly, and whose authors have never stated that they have made use of it. Including such texts creates a potential vagueness and breadth of subject matter that I wish to avoid. I investigate a far more targeted set of texts that signal themselves as stories of quantum physics by explicit reference: I wish to investigate how using quantum physics raises expectations, and shapes and directs narratives. One can see

³² Front, 77.

³³ David Mitchell, *Cloud Atlas* (London: Sceptre, 2004), 158.

³⁴ David Mitchell, ‘Guardian Book Club: Cloud Atlas by David Mitchell’, *The Guardian*, 12 June 2010, sec. Books, <https://www.theguardian.com/books/2010/jun/12/book-club-mitchell-cloud-atlas>.

why Sokal and Bricmont might be annoyed at the way in which quantum physics theories are abused in some works of both literature and literary criticism: the term 'quantum' has frequently been associated with concepts that have absolutely nothing to do with the physics, leading to widespread misunderstanding.

As indicated in Chapter 1, the disagreements regarding different interpretations of quantum physics, especially the Copenhagen and many-worlds interpretation, are made evident in textbooks and most popular books. Similarly, nearly all the works discussed in this chapter deliberately side with one or another particular interpretation. The three interpretations that come to the fore in fiction are the conscious collapse interpretation (Bonta, *Flight*; Egan, *Quarantine*), the Copenhagen interpretation (Walton, *Superposition*), and the many-worlds interpretation (Norton, *The Crossroads of Time*; Crouch, *Dark Matter*; Hoyle, *October the First is Too Late*; Benford, *Timescape*; Pears, *Arcadia*).

The Conscious Collapse Interpretation

The idea that everything in the universe exists as a wavefunction in many different potential realities, 'eigenstates', until observation by a conscious entity causes it to 'collapse' and become real, is a controversial view among quantum physicists. As discussed in Chapter 1, pseudoscience has seized upon the opportunity to present the conscious collapse interpretation as a scientific theory that supports belief in the existence of the soul as something granted only to humans to make the universe real, and/or in God as the ultimate conscious observer. Both the conscious collapse and the many-worlds interpretation occupy a fringe position within the scientific establishment, yet the former

seems to have been embraced by pseudoscientific writers more so than the latter, which may have caused physicists to avoid it in their popularizations.

One of the few authors to use this interpretation in a non-mystical way in fiction is Greg Egan. In *Quarantine* (1992), the first instalment of his 'hard' science fiction series *Subjective Cosmology* (1992-1995), he introduces the concept of the conscious collapse of the wavefunction in order to create an original narrative around probability, death, and suicide. After the physicist Po-kwai proves that the human brain is indeed responsible for the collapse of the wavefunction, the first-person protagonist, Nick Stavrianos, obtains a brain modification with which he can prevent his own wavefunction from collapsing. Nick is now able to 'smear' himself out over different eigenstates, and is able to perform different actions simultaneously in each eigenstate, before collapsing into the most ideal reality. In a test, Nick is able to instantly open a combination lock with a ten-digit code, because each eigenstate is able to enter a different number, until the wavefunction collapses into the version of Nick who has guessed the code correctly. In the novel, this collapse is represented with jumps in the narrative: the reader follows Nick entering the code 1450045409 into the lock, but when the lock opens, they read that the code was 9999999999.³⁵ The collapse has taken place outside the narrative: the only instance of Nick that is left becomes the focalizer.

This ability to collapse at will becomes useful for Nick when he needs to prevent his antagonist, Lui Kiu-chung, from releasing a nanomachine virus epidemic that will allow everyone on the planet to prevent their wavefunction from collapsing. Nick does not know where to find Lui, but is able to smear himself out and try all of the options

³⁵ Egan, *Quarantine*, 152.

at once; the option that leads to Lui is the one onto which he will end up collapsing his wavefunction. As long as Nick can keep entering a superposition state, he can explore different branches of the narrative. The reader thus sees him kill Lui, but on the next page, Nick does not draw his gun in time and Lui manages to throw the virus vial out of the window.³⁶ The virus escapes into the city of New Hong Kong, Australia, which is not the most desirable outcome for Nick, but it is the most desirable for all minds in New Hong Kong. Everyone in the city enters a superposition state: Nick and Po-kwai discover that this outcome has been selected by this collective superposition of minds.³⁷ This superposition, however, chooses suicide, making itself collapse: 'Smearing is exponential growth, increase without bounds. A single, unique reality was the only stable alternative. There could be no middle ground.'³⁸ The psychological pressure brought on by a limitless malleability of both oneself and the world became too much to bear.

Quarantine questions the concept of identity under the conscious collapse interpretation through focalization. The first-person narration only allows the reader to see one perspective at a time, yet the focalizer can change from one paragraph to the next – it is clear that there is no logical continuity between Nick killing Lui and Nick failing to fire his gun in time. These are two different focalizers, even though they both claim to be Nick, the first-person narrator, the 'I.' Yet the multiplicity of characters is not presented to the reader all at once: the focalizer is one person at a time, presenting the subjective singular experience of one particular Nick. The reader will question the

³⁶ Egan, 206–7.

³⁷ Egan, 214–17.

³⁸ Egan, 218.

reliability of the first-person narrator once it is clear that the next sentence might be written from a different perspective owned by the same narrative agent. *Quarantine* thus expresses one way in which quantum physics questions the concept of identity and of being a single, independent self.

Egan published a blog post about *Quarantine* in which he explains where exactly he deviated from accepted scientific theory. He stresses that his use of this particular interpretation, which he does not name, ‘was chosen solely for its technological and existential ramifications, not because I considered it plausible.’³⁹ He stresses several times that he has selected this interpretation only for the fictional possibilities it opens up, not because of its factual accuracy or support among scientists:

though this hypothesis leads to some entertaining consequences, I don’t actually believe it for a moment. What’s more, I’m not sure how seriously any physicist has ever really taken [this position] at all. [...] the point I want to stress is that positing a role for *an observer* in the collapse — as opposed to a role for *any* macroscopic system that is affected by the quantum system — is a marginal view. I suspect part of the reason that it lives on even now in some popular accounts of quantum mechanics is actually due to proponents of [the Copenhagen interpretation] being mistakenly lumped in with [this position].⁴⁰

Egan emphasizes that his work is purely fictional and does not reflect his personal scientifically informed views as to which interpretation of quantum physics is likely to be correct; he is using the conscious collapse interpretation in order to make a new kind of fictional narrative possible. The consequences of Egan’s choice of interpretation for the plot and structure are clearest when compared to works that make use of the Copenhagen interpretation.

³⁹ Egan, ‘Quantum Mechanics and Quarantine’.

⁴⁰ Egan.

The Copenhagen Interpretation

Several recent novels make use of the Copenhagen interpretation to structure their narratives, using the concepts of superposition and the collapse of the wavefunction to question the concepts of identity, focalization, and death. This interpretation was also used by science fiction authors who wished to use cutting-edge physics in their works before 1957. Both John Gribbin and Patricia Warrick claim that the first science fiction work to make use of quantum physics is a many-worlds narrative by Jack Williamson.⁴¹ ‘The Legion of Time’ was originally published in *Astounding Science Fiction* in 1938; under the same title, the story was published together with ‘After World’s End’ in book form in 1952. Gribbin in particular argues that the story uses the many-worlds interpretation in a way that ‘really does anticipate the advance of theoretical science’⁴²; however, Williamson arguably makes use of the Copenhagen interpretation, as a collapse of multiple potential future realities takes place in the narrative. The mathematician Wil McLan explains the quantum physics of the first half of the twentieth century to the protagonist, Denny Lanning: ‘But Max Planck came along with the quantum theory, de Broglie and Schroedinger and their wave mechanics, Heisenberg with his matrix mechanics. Every new discovery seemed to complicate the structure of the universe – and the problem of time.’⁴³

Rather than proposing a branching network of different histories from a shared origin, Williamson proposes the concept of future possible worlds. McLan connects this

⁴¹ Warrick, ‘Quantum Reality in Recent Science Fiction’, 303; Gribbin, *In Search of Schrödinger’s Cat*, 372.

⁴² Gribbin, *In Search of Schrödinger’s Cat*, 372.

⁴³ Jack Williamson, *The Legion of Time* (1952; repr., London: Sphere, 1977), 34.

concept to the possibility that the observer causes a collapse. Only one of all the existing possible futures can become real, and when he observes a dystopian future world, Gyronchi, his observations cause Gyronchi to become real:

no process whatever can reveal the state of an electron without changing that state. The quanta of my scanning ray were absorbed by the atoms that refracted them. The result was an increase in the probability factor of Gyronchi – that is the root of all the tragedy.⁴⁴

Notably, living humans cannot travel between these future possible worlds: Denny needs to die before he can make the journey to save the worlds. The novel uses quantum physics in an allegory for the arduous journey a soul must take to be allowed to enter Heaven. The references to real science allow Williamson to warn the reader against the abuse of this science: McLan is the archetypal curious but careless scientist, who by following the principles of modern science almost unleashes Hell on his fellow humans by not thinking through the consequences of his curiosity.

The Copenhagen interpretation has not been entirely replaced in fiction by the more narratologically attractive many-worlds interpretation. David Walton, trained as an engineer, used the Copenhagen interpretation for his duology *Superposition* and *Supsymmetry* (both 2015). Using the principles of superposition and the collapse of the wave function, the author is able to write a detective story through the eyes of one protagonist, but from different perspectives. In the near future, physicist Brian Vanderhall visits his former colleague Jacob Kelley to prove that he is in contact with so-called ‘quantum intelligences,’ nicknamed the *varcolac*, that allow him to demonstrate quan-

⁴⁴ Williamson, 37.

tum physics effects at the macro scale. The next day, Jacob finds Brian dead at his workplace, the New Jersey Super Collider, only to find him alive again in the back of his own car. Brian is in a state of superposition; when his wavefunction collapses, the only Brian that is left is the dead one. Jacob and his family, meanwhile, have also entered a state of superposition: one Jacob is arrested for murder in front of his family, but the other Jacob escapes with his daughter Alessandra after the *varcolac* kills his wife and other children. The structure of the novel reflects this split: the odd chapters, all called 'Up-spin', depict Escaped Jacob's story, and the even chapters, all called 'Down-spin', narrate Arrested Jacob's story.

The reader learns about quantum physics alongside the jury that will determine Arrested Jacob's fate. Arrested Jacob and his lawyer Terry Sheppard need to convince the jury that the quantum physical effects that have influenced Jacob and Brian's lives are real. Quantum physics is put on trial, and the reader is made to take up the position of the jury. The reader of course believes Jacob's side of the story, having witnessed the events of the previous chapters through his eyes; therefore, they must also side with the idea that quantum physics and its effects as predicted by the Copenhagen interpretation are real. The prosecution claims that the technobabble will turn their heads:

'Mr. Sheppard is going to try to convince you that this case is about technology. He's going to make your mind spin with words like 'quarks' and 'leptons' and confuse the facts with expert testimony about science that only a few people in the world understand. [...] In our great country, we don't believe the highly educated or the very rich are more qualified to find the truth than you are.'⁴⁵

⁴⁵ David Walton, *Superposition* (Amherst, NY: Pyr, 2015), 19.

Sheppard, however, flatters the jury by explaining to them that they can indeed understand the scientific explanations.

'I am going to cover a lot of science in my side of the testimony, and some of it can get a bit complicated. The difference is that, unlike Mr. Haviland, I think you can handle it.

*Mr Haviland seems to believe that you're not smart enough to understand science. He wants to spoon-feed you only the bits he thinks you can grasp. Personally, I find that kind of condescension offensive, but he's entitled to his opinions. What he's not entitled to do is withhold from you all the facts of the case. He's not entitled to decide that there are some facts you're not qualified to understand.'*⁴⁶

Sheppard makes the trial a test of democracy, even as Haviland is relying on US democratic principles to support his argument to exclude science from this trial. The reader is persuaded, along with the jury, that they indeed can understand the explanations that will follow. Of course, Sheppard too is only going to feed the jury (and thus the reader) the bits of the science he thinks they can grasp, as shown by a passage in which Sheppard, Arrested Jacob and Jean, another physicist colleague of Jacob, are preparing the scientific explanation that Jean is going to give at the trial:

'They just need to get the idea that something can be in two states at once,' I [Jacob] said. 'They don't have to understand it entirely, but they have to believe it as a thoroughly tested and noncontroversial finding of modern science. So how do we do that? Quote Einstein? Cite polls of leading scientists?'

*'None of that matters to a jury,' Terry said. He pointed at Jean. 'What matters is her. If she can sell it, and not let Haviland talk her in circles or undermine her credibility, then they'll accept it as fact.'*⁴⁷

The reader witnesses both the rehearsal and the trial, and is thus given an extremely detailed explanation.

⁴⁶ Walton, 21.

⁴⁷ Walton, 74.

Singling out these sections gives the impression that Walton is masking a popular science book as fiction, but the expositions serve a higher purpose for the fiction: quantum physics needs to be explained in order for the most compelling parts of the plot to develop in a way that is understandable to the readers. Since Walton's works are published by Pyr, a dedicated science fiction and fantasy imprint, it is likely that both the author and the publisher expect the reader to be familiar with infodumps. However, the discursive form of exposition displayed in the three block quotations above is a common feature of nearly all works discussed in this chapter, whether they are marketed specifically as science fiction or not. The reader is typically informed about the science underpinning the narrative in a dialogue between a physicist and the most important non-physicist character: Po-kwai and Nick in *Quarantine*, Jean and Terry in *Superposition*, Alex and Sandra in *Supersymmetry*, Jason and Amanda in *Dark Matter*. Many of these dialogic interactions can be characterized by Sean Kinch's judgment of the infodump in another fictional work that uses quantum physics: 'The aridness of that passage, which sounds like excerpts from a popular science book, seems unrealistic as speech when taken out of context'.⁴⁸ However, the dialogue-heavy interactions, even as they feel contrived, create a vital expositional context: one in which mathematics is avoided.

Most of *Superposition* focuses on the Copenhagen interpretation and the principle of superposition. The Copenhagen interpretation demands that the two or more different states that Brian, Jacob, and Alessandra find themselves in will eventually

⁴⁸ Kinch, 'Quantum Mechanics as Critical Model', 299.

have to resolve. Later on in the book, the many-worlds interpretation is also introduced, when Brian mentions that ‘Every decision you make is made the other way by another version of you in a parallel universe.’⁴⁹ However, at the climax of the novel, when it is revealed that Jean is a villain, the two interpretations that Walton presents, conflict. The revelation that Jean is a villain may surprise the reader of *Superposition* due to a long history in both science fiction and mainstream fiction depicting scientists, especially villainous ones, as male.⁵⁰ However, she soon turns from a non-stereotypical female scientist villain to a stereotypical desperate mother. She uses Brian’s quantum technology to improve the quality of her life as a mother: she is able to ‘manipulate the Higgs field’ to access a parallel world in which her child does not have Down syndrome and swap the two babies. Jacob explains to Jean’s husband Nick that ‘the Higgs field extends across multiple universes. [...] It means she can access alternate versions of your daughter. [...] It means she can retrieve versions of your daughter that might have been if different choices had been made...’⁵¹

Shortly afterwards, the narrative favours the Copenhagen interpretation again, when Jacob’s wife and children end up in a Schrödinger’s Cat-like situation. The cat paradox is quickly explained in two infodump paragraphs; the explanation assumes the Copenhagen interpretation, with the system described by ‘a probability wave that had not yet collapsed.’⁵² Since his family is currently both dead and alive at the same time, Jacob realises that there is a 50% chance that his family will be dead when he finds and observes them. He hesitates: ‘The thought crossed my mind that I should stop digging,

⁴⁹ Walton, *Superposition*, 85.

⁵⁰ Haynes, *From Faust to Strangelove*. I do not expect my readers, who have just come across Mrs Coulter in Chapter 5, to be equally surprised to see a female evil scientist.

⁵¹ Walton, *Superposition*, 269.

⁵² Walton, 292.

that it was better to be caught in a state between life and death than to be completely and irreconcilably dead.⁵³ The novel finds itself in a contradiction: the narrative is made more exciting by positing that Jacob is somehow in control of his family's fate. However, Jacob's dilemma does not take into account an issue already inherent in Schrödinger's cat paradox: the idea that Jacob's family, observing themselves, would have already caused a collapse. Whereas one might debate whether a cat can count as an observer, all interpretations agree that humans are valid observers. Refusing to observe his family only results in Jacob not knowing what happened to them. Scientific accuracy is subordinate to narrative requirements; at the same time, the idea that these action-packed events are based on real scientific knowledge itself adds to the impact of the narrative.

Superposition and *Supersymmetry* were published in the same year. Whereas the first title referred explicitly to a quantum mechanical phenomenon that was key to the plot, supersymmetry is a particle physics phenomenon that is not necessarily connected to quantum physics, and which does not feature at all in the novel. Having a title that resembles that of the first novel seems to have been more important than maintaining the connection to the quantum physical contents of the novel. The sequel is set fifteen years after *Superposition*. Although the superposition of the two Jacobs collapsed at the end of *Superposition*, in *Supersymmetry* Alex and Sandra Kelley are still two separate people, living drastically different lives as a physicist and a police officer. They are still terrified of what might happen to their personal identities if their superposition should ever collapse. Jean's two roles are repeated: she first enters the story

⁵³ Walton, 292.

as an explainer, someone who is able to understand the mechanics of the *varcolac*, but then becomes the transgressor, willing to murder all others to become the chosen one to receive the knowledge of the *varcolac*. In the sequel, Jean's actions are no longer those of a desperate mother, but rather those of the overly ambitious scientist usually depicted as male in fiction.

David Walton and Greg Egan show how adherence to a specific interpretation of quantum physics can influence not only the structure of a narrative, but also character development and psychology. Both Egan and Walton investigate the concept of identity by means of a first-person singular narrative in which the narration shifts between different focalizers who are the same person. However, when Nick in *Quarantine* smears himself out over several different eigenstates, the reader only ever follows one eigenstate at a time, thus maintaining a singular sense of identity. Nick cannot remember the paths the other Nicks have explored after the wavefunction collapses, and the perspective of a focalizer whose wavefunction has collapsed will not be accessible again. He cares little about these other Nicks, as their 'deaths' are an affirmation that the current focalizer is succeeding against enormous odds. Walton's characters, on the other hand, obtain separate identities when they undergo superposition, which leads to tension in the narrative. These characters remember what has happened to each separate person, thus making sure that the reader does not remember more than the characters do. Throughout *Superposition*, therefore, there are two focalizers who are both Jacob, and whose perspectives are accessed in alternate chapters. For Nick in *Quarantine*, it is not relevant what the other Nicks have done, so the reader can stick to a single narrative and focalizer; for Jacob and Alex/Sandra/Alessandra, it is relevant, so the novel must be able to combine multiple narrative threads. In *Supersymmetry*, the

storylines of Alex, Sandra, and Alessandra are narrated in the third person, emphasizing their identities as two separate individuals who merge at the end of the novel into a third, new, character.

Contrary to *Superposition*, *Supersymmetry* rejects the many-worlds interpretation outright. After the superposition of Alex and Sandra collapses and they become Alessandra again, she explains that

‘the multiverse theories have always been a bit fanciful. It’s hard to believe that entirely new universes are being created all the time, whenever any particle’s probability wave collapses. The math certainly doesn’t require it. [...] There’s only one timeline. The universe solves the equation so that causality is preserved.’⁵⁴

Alessandra’s explanation contradicts the information given in the first novel, without acknowledgement, yet it corrects the paradoxical application of both the Copenhagen interpretation and the many-worlds interpretation in the previous novel. Jean’s attempt to change her child is now explained as time travel rather than accessing multiple worlds: ‘She had tried to use the Higgs projector to change the past, to alter the fall of the dice, and resolve her unborn daughter’s probability wave as a healthy, able child.’⁵⁵ This approach is explained at the end of the book, when Alessandra uses it herself to change the past and prevent a nuclear world war instigated by the *varcolac*. Truly changing the past would not have been possible under the many-worlds interpretation, in which she would have created a new branch; there would still be a parallel universe that would suffer a nuclear war. Walton moves from the many-worlds to the Copenhagen interpretation in order to create an unambiguously positive ending.

⁵⁴ David Walton, *Supersymmetry* (Amherst, NY: Pyr, 2015), 273–74.

⁵⁵ Walton, *Superposition*, 162.

Although it may sound odd that Walton would have his characters abandon the many-worlds interpretation after they have used technologies that assume it to be true, we will see that he is not the only one to have done so. Iain Pears's *Arcadia* similarly makes use of many-worlds travel that turns out to be time travel. In Gregory Benford's *Timescape*, the opposite applies: the suggestion is initially made that the physicists are changing their own past, but it is eventually revealed that they have created a better future for a parallel universe. Quantum physics occupies an uncertain position in our own time, where we do not know which of many different possible interpretations could turn out to embody the truth. Fiction is therefore able to present a near-future world in which the correct interpretation is only just being discovered; such fiction can even be set in the far future. These narratives of discovery can be written as a mystery or detective plot, with unexpected outcomes and sudden plot twists.

The Many-Worlds Interpretation

Hugh Everett's many-worlds interpretation has been to date the most influential interpretation of quantum physics in fiction. Since not many fiction authors are trained as scientists, and even fewer are trained specifically as physicists, the strong bias toward the many-worlds interpretation in popular science books might be one reason why this bias also exists in fiction. The many-worlds interpretation also connects to existing narrative tropes in many ways, which makes it an interesting interpretation to communicate in popular science books as well as a useful one for fiction. As Marie-Laure Ryan points out, narratives that make use of the Everettian multiverse overlap with three

fiction tropes in particular: transworld exploration, time travel, and alternate history.⁵⁶ The many-worlds interpretation has the ability to provide a scientific validation for these three existing modes, lifting them out of the realm of fantasy and giving a more realistic potential to them. However, using the many-worlds interpretation as a trope can do much more. The works discussed here use the many-worlds interpretation in such a way that the science plays a significant part in the construction of the narrative, both at the level of the structure and at the level of the narrative itself.

Gregory Benford's *Timescape* (1980) makes use of both special relativity and of quantum physics to combine time travel and alternate history, also known as counterfactual history,⁵⁷ in a science fiction novel. In the novel, physicists discover the possibility of time travel in 1998, but cannot physically travel; instead, they send a message back to the 1960s to prevent the ecological catastrophe that endangers their world. To make this plot possible, Benford makes use of tachyons, hypothetical particles that can travel faster than light and therefore backwards in time. The tachyon is a striking example of physics and science fiction influencing each other. Being inspired by James Blish's 1954 story 'Beep', in which messages from the future arrive through faster-than-light travel, Gerald Feinberg coined the name of the particle in a 1967 paper titled 'Possibility of Faster-Than-Light Particles'. The term subsequently gained widespread renown through Blish's use in the 1970 Star Trek novel *Spock Must Die!* Tachyons thereafter became a frequently alluded-to concept in Star Trek.⁵⁸

⁵⁶ Ryan, 'From Parallel Universes to Possible Worlds', 656.

⁵⁷ Janice Liedl, 'Tales of Futures Past: Science Fiction as a Historical Genre', *Rethinking History* 19, no. 2 (3 April 2015): 291, <https://doi.org/10.1080/13642529.2014.973710>.

⁵⁸ James Blish, 'Beep', *Galaxy Magazine* 7, no. 5 (February 1954): 6–44; Gerald Feinberg, 'Possibility of Faster-Than-Light Particles', *Physical Review* 159, no. 5 (1967): 1089–1105, <https://doi.org/10.1103/PhysRev.159.1089>; James Blish, *Spock Must Die!: A Star Trek Novel* (Toronto: Bantam Books, 1970).

In *Timescape*, the lives of the people sending the message will not be affected by its consequences; instead, they hope to have established a better future for people on an alternate timeline. Benford, who is a professor of physics as well as a science fiction author, does not refer to Everett anywhere. Instead, he lets his character Gregory Markham discover this interpretation: 'Markham felt a sudden stab of perception. If the universe was a wholly linked system with no mythical classical observer to collapse the wave function, then the wave function did not have to collapse at all.'⁵⁹ Markham builds on the work of a scientist called Tanninger, who created a new function that

did not describe probabilities – it spoke of different universes. When a loop was set up, the universe split into two new universes. [...] All this came from using tachyons to produce the standing-wave kind of time loop. Without tachyons, no splitting unto different universes occurred.⁶⁰

Since Everett's supervisor John Wheeler, alongside more than a dozen other physicists, is mentioned by name in the novel, Everett's absence is remarkable. It is unlikely that Benford had not heard of Everett by 1979; as explained in Chapter 1, by then Wheeler had already endorsed Everett, leading to a surge in the dissemination of his ideas. Leaving Everett out allows Benford to create a version of the many-worlds interpretation that would fit his story more closely through merging the already popular science fiction concept of the tachyon with a new interpretation of quantum physics, which together would allow for the sending of the message to the past.

Andre Norton's *Crosstime* duology, which consists of *The Crossroads of Time* (1956) and *Quest Crosstime* (1965),⁶¹ perhaps comes closest to showing how well the

⁵⁹ Benford, *Timescape*.

⁶⁰ Benford.

⁶¹ Andre Norton, *The Crossroads of Time* (1956; repr., New York: Ace Books, 1978); Andre Norton, *Quest Crosstime* (New York: Ace Books, 1965). Norton first adopted the masculine first name Andre as a pseudonym; she later legally changed her first name, Alice, to Andre.

many-worlds interpretation works as an alternate-history narrative trope. In the first instalment, published a year before Everett's paper, she invents a similar theory, although not grounded in mathematics, to enable a science fiction narrative. In this duology, the "'possibility worlds" theory of history' is invented by historians, rather than scientists. When Blake Walker, the protagonist, first hears about this theory, he remembers reading 'some fantasy fiction founded on [...] the idea that two complete worlds stem from every momentous historical decision.' He is then told that the 'possibility worlds' theory is different because it suggests that 'There would be myriad worlds, all influenced by various decisions. Not only by the obvious ones of battles and political changes, but even by the appearance and use of certain inventions.'⁶² In *The Crossroads of Time*, Blake meets a group of men who first claim that they are from the FBI; when they discover that Blake has 'psi' powers – such as telepathy and telekinesis – they reveal that they come from a parallel universe where humans have developed such powers. Erskine, Hoyt and Saxton, as they call themselves on Earth, are on the hunt for a man named Kmoat Vo Pranj, who travels to parallel worlds that are in political turmoil, to abuse his psi powers and rule over these worlds. Blake eventually comes across one of the devices that is used to travel between worlds, ending up first in a world where metal dinosaurs exist. It is never explained how that world is related to ours, making the introduction of Norton's 'possibility worlds' theory seem rather unnecessary. However, the purpose of the introduction of this branching becomes much clearer when Blake arrives in a world where Hitler won the Battle of Britain.

⁶² Norton, *The Crossroads of Time*, 18–19.

As shown by the ‘fantasy fiction’ Blake refers to in *The Crossroads of Time*, the concept of alternate universes created at key moments in history is a well-known fictional trope; a very popular version is an alternate history in which the Nazis have won the war. This trope has been used since the second half of the twentieth century, from C.S. Forester’s ‘If Hitler Had Invaded England’ (1960) and Philip K. Dick’s *The Man in the High Castle* (1962) to Robert Harris’s *Fatherland* (1992) and Éric-Emmanuel Schmitt’s *La part de l’autre* (2001).⁶³ Tom Shippey ascribes its enduring popularity to the possibilities the trope opens for a conflict between ‘Whig history’, which ascribes an important role ‘to individual heroes’ and ‘Malthusian history’, which assumes ‘that societies are bound together by very powerful forces’.⁶⁴ This conflict leads to a ‘tension between “desirability” and “possibility”’.⁶⁵ The forking point at a key moment in history influences the ‘possibility’ factor: here is a point where it is easy for the reader to believe that one individual may be able to change the outcome in a way that will have monumental consequences for world history. Authors are then able to explore whether this change was indeed desirable, or whether society has not changed as much as expected.

⁶³ C.S. Forester, ‘If Hitler Had Invaded England’, *Saturday Evening Post*, 30 April 1960; Philip K Dick, *The Man in the High Castle* (1962; repr., London: Penguin Books, 2001); Robert Harris, *Fatherland* (1992; repr., New York: HarperTorch, 2002); Éric-Emmanuel Schmitt, *La part de l’autre* (Paris: Albin Michel, 2001). Shippey points out that the most famous alternate history trope before the Second World War was that of the Confederacy winning the American Civil War. Tom Shippey, ‘Alternate Historians: Newt, Kingers, Harry and Me’, in *Hard Reading: Learning from Science Fiction* (Liverpool: Liverpool University Press, 2016), 124–40, p. 129.

⁶⁴ Tom Shippey, ‘Science Fiction and the Idea of History’, in *Hard Reading: Learning from Science Fiction* (Liverpool: Liverpool University Press, 2016), 70–84, p. 74.

⁶⁵ Shippey, p. 83.

The aforementioned novels posit their alternate universe as the only real universe, whereas Norton presents the two worlds as true parallels: both versions of reality exist at the same time. To make this concept sound plausible, she required the introduction of the possibility-worlds theory, as opposed to starting the story *in medias res* in the alternate universe. That Norton's possibility-worlds theory is not the same as the many-worlds interpretation is shown in two distinct ways. Firstly, the worlds in Norton's duology are literally parallel. The worlds can only be travelled through in a distinct order. In *Quest Crosstime*, Blake's ship crashes halfway through a world transfer, and he is able to deduce which world they could be on from the length of their trip: 'There was a series of successor worlds at this end of the crosstime swing, none of them too well-known until one reached the Forest level.'⁶⁶ The sequential layering of the worlds prevents time travel: 'One did not go forward or backward in time by the route of the successor worlds – only across it.'⁶⁷ Making time travel impossible in her narrative leads Norton out of the bind that Blake faces when he enters the world in which Hitler has conquered Europe: it is not possible for Blake to go back in time in this world, or any other, to stop Hitler, which also means that the crosstime travellers cannot wilfully create new parallel universes at moments of historical importance.

The second way in which Norton's 'theory' is different from Everett's later one is shown in the fact that Erskine and his colleagues wish to deter Pranj from achieving his goal of world(s) domination. Under the many-worlds interpretation, the hunt for Pranj would simply lead to many more branches in the multiverse, in some of which Pranj would rule his world, and in some of which he would be captured, whereas in

⁶⁶ Norton, *Quest Crosstime*, 38.

⁶⁷ Norton, *The Crossroads of Time*, 144.

others none of these people would enter that particular world at all. In most post-Everett works that explicitly make use of his interpretation, this aspect is not touched upon in order to present a positive ending.

As Borges's story has already indicated, another element of the many-worlds interpretation that is incompatible with storytelling is the fact that the theory in its fullest sense predicts an infinite number of worlds, with worlds splitting every time the Copenhagen interpretation states that a collapse would take place. Such frequent branching leads to unimaginably many worlds, including billions that would not noticeably differ from ours. In fiction, only those worlds which are markedly different are interesting: in *The Crossroads of Time* and *His Dark Materials*, the different parallel worlds are populated with lifeforms that do not exist in our world. The author needs to find a way to enable the characters to reach these interesting worlds, rather than having them drift through millions of uninteresting ones. In *His Dark Materials*, Will is able to feel the difference between worlds when testing the air with his knife, thus finding the ones he and Lyra need, such as the underworld. Norton lets technological innovations limit inter-world travelling to select worlds: she makes inter-universe travelling only possible by means of a rather simple apparatus that has a lever pointing to different notches, each standing for one world.

As Chapter 1 showed, the many-worlds interpretation proved less popular with physicists than the Copenhagen interpretation. Even so, physicists, too, acknowledged its power as a literary trope. Fred Hoyle's popular radio lectures, in which he expresses his preference for the steady state theory, were discussed in Chapter 3. Hoyle also wrote science fiction, in which his preference for many-worlds over Copenhagen for

narrative purposes is made clear.⁶⁸ In *October the First is Too Late* (1966), a musician and a physicist witness an alien intelligence splitting up Earth into different time zones – in Britain it is 1966, in France it is 1917, and in Greece, it is 450 BCE. The physicist, John Sinclair, finds that he is able to explain these events through relating them to quantum physics concepts. Hoyle first seems to adhere to the conscious collapse interpretation, and his is the earliest work of fiction I have identified that mentions the influence of consciousness on wavefunction collapse. Sinclair explains to Dick, the musician: ‘The thing that gives the answer isn’t the camera or the counter, it’s the actual operation of looking yourself at the equipment. [...] I’m talking about quantum theories now.’⁶⁹ However, Sinclair’s further explanation of the physics behind the events is mostly based on the many-worlds interpretation: ‘Hook up a bomb which explodes according to whether you have decay of a nucleus or not. [...] My guess is that inevitably we appear to survive, because there is a division, the world divides into two, into two completely disparate stacks of pigeon holes.’⁷⁰ Hoyle’s interpretation lies closer to the many-worlds interpretation than to the standard alternative history trope through the way he constructs the point at which the worlds separate: the split suddenly occurs during a camping trip in Scotland, rather than at the point of a momentous decision or event in history. That Hoyle uses his knowledge of physics deliberately is explained in a short preface: ‘The “science” in this book is mostly scaffolding for the story, storytelling in the traditional sense. However, the discussions of the significance of time and

⁶⁸ One might be tempted to equate Hoyle’s stubborn adherence to the wrong astrophysical theory – the steady-state theory rather than the big bang – to his use of the Everett interpretation, an ‘underdog’ theory within quantum physics. However, it must be born in mind that, first of all, Hoyle was an astrophysicist and not a quantum physicist, and secondly, the Everett interpretation appears in one of his works of fiction rather than in his popularizations.

⁶⁹ Hoyle, ‘October the First Is Too Late’, 297–98.

⁷⁰ Hoyle, 322.

of the meaning of consciousness are intended to be quite serious.⁷¹ Hoyle, then, uses quantum physics as Ryan has described it, in a manner that is similar to a traditional narrative trope, while at the same time explicitly making the reader aware of the fact that the events in this story are different from those of traditional stories in their use of modern science.

The many-worlds interpretation also enables a new exploration of another fiction trope: it facilitates an exploration of a character's identity and personality by allowing a character to encounter a different version of themselves. H.G. Wells's *A Modern Utopia* is one example of a pre-quantum physics application of this trope.⁷² Blake Crouch's 2016 science fiction thriller *Dark Matter* presents, just like *Superposition*, a protagonist who is a loving father and husband, and an unspectacular physicist.⁷³ Published by Crown in the US and Macmillan in the UK, the novel is not specifically marketed at readers familiar with hard science fiction tropes. One night, Jason Dessen, who is the first-person narrator, is kidnapped by what turns out to be a parallel-world version of himself. Jason2, as the narrator calls him, is in his world a famous physicist who has managed to invent parallel-world travel; however, he has sacrificed the chance to have a family for this success. As Jason2 tries to take over Jason's place in his world, Jason escapes, aided by the psychiatrist Amanda. They use the parallel-world travelling box to get Jason back to his own world, ending up in one wrong world after another.

⁷¹ Hoyle, 254.

⁷² H.G. Wells, *A Modern Utopia* (London: Chapman and Hall, 1905).

⁷³ Crouch, *Dark Matter*. The concept of dark matter is not relevant to the narrative. The link between the Everett interpretation and dark matter is only made once, and left unexplained: 'Some string theorists think it [dark matter] might be a clue to the existence of the multiverse' (112). In what way dark matter might be a 'clue' is not addressed.

In contrast to the many Nicks in *Quarantine* and the two Jacobs in *Superposition*, the multiple versions of a character that are created through multiverse branching in this novel are all permanently real and separate. When Jason finds himself back in his own universe, he discovers that he is not the only one to have made it there: over the course of his adventures, new parallel universes with new Jasons have continued to come into existence. They all have Jason's history and memories, so they all share the same goal of getting back with his wife and child. Jason meets one of these versions of himself at a bar:

This man and I were the same person up until a month ago. Which means ninety-nine-point-nine percent of our history is shared. [...]
 As he buys our second round of beers, I can't take my eyes off him.
 I'm sitting next to me.
 There's something about him that doesn't seem quite real.
 Perhaps because I'm watching myself from an impossible vantage point – looking at myself from outside myself.⁷⁴

The English language cannot fully represent the situation: Jason swerves back and forth between the first and third person as he identifies himself with, then dissociates from, the other Jason.

The constraints of the narrative structure the author has chosen limit this blurring and questioning of identity. Throughout the novel, the same Jason is the focalizer. Unlike Nick in *Quarantine*, a switch in perspective between these two Jasons would imply a change in narrative agent. Despite the frequent encounters with other Jasons that are as good as identical to the focalizer, this narrative technique directs the reader's sympathies. The reader has built up a bond with this narrator, and will continue to root

⁷⁴ Crouch, 270. It is a stylistic feature of *Dark Matter* to have nearly every sentence start on a new line.

for him, hoping that he will have the happy ending with his wife and child, rather than any of the other Jasons. The Jasons are theoretically and physically identical, but the form of the narrative presents one as special. It is no surprise that the narrator is indeed the Jason who ends up escaping with his wife and son: this happy ending definitively distinguishes Jason from all the other Jasons, confirming that he was indeed special, and more ingenious than the others. The split-selves device has only limited applicability in a chronologically told narrative of limited length and scope: the reader is unable to build up the same bond with any of the other Jasons. The Jasons are identical from the perspective of the characters in the novel, but not from the reader's perspective.

Iain Pears's *Arcadia* (2015) is one of the few works that borrows concepts from quantum physics not only for the contents of the narrative, but also for its structure. The work was originally intended to be available only as an iOS app in a collaboration between Faber Digital and Amphio,⁷⁵ but most of the contents of this app have also been published as a printed novel with an imposed reading order. *Arcadia* soon introduces the concept of parallel worlds and the idea of travelling between them. Part of the book is set in the year 2222, when the physicist Angela Meerson discovers an inter-universe travelling method. However, she is convinced that what is actually made possible is time travel:

‘This whole project is based on the assumption that what we are doing is not time travel. Laws of physics. Accepted and proven for two centuries or more. All we can possibly do is transit to a parallel universe. Right?’ [...] ‘Wrong,’ I went on. ‘Wrong, wrong. It’s all wrong. I know it is. Think. In theory, we should be able to access any number of universes. So why can we only seem to access one, eh? No one has thought about the implications of that. I think the whole alternative

⁷⁵ Iain Pears, ‘Arcadia’, accessed 2 September 2016, <http://arcadiatheapp.com/>.

universe theory is complete nonsense. We would be moving in this universe. The only one there is. Time travel, to put it bluntly. If that is the case, we have to stop now.’⁷⁶

In Angela’s time, the ‘multiple universe theory’ has been the ‘accepted convention for nearly two hundred years.’⁷⁷ Angela is the one who now proves this interpretation wrong, as she shows how people can travel back and forth on a single timeline, which does not branch; however, she is not believed. The question of whether the world she and her colleagues have discovered, Anterwold, is their own future or a parallel world becomes particularly pressing as her colleagues decide to destroy this world with nuclear weapons to create more living space for themselves.

The conflict between these two interpretations, the many-worlds interpretation and the idea of a single timeline on which one can move back and forth, is reflected in the structure of the app version of *Arcadia*. The narrative in this app, which is longer than the novel, is broken up into short sections, at the end of which the reader is given the opportunity to select which section to read next, from a limited range of up to seven options. The reader can choose to follow the storyline of one character, or switch between characters; in most cases, following one single character strand from beginning to end will not provide enough information to understand the plot. The characters are not identified by their name in the superstructure, but by their identities: *Canterbury Tales*-like, the different strands are called The Teacher’s Tale, The Scientist’s Tale, The Young Girl’s Tale – there are ten strands in total, containing between sixteen and seventy-three sections per strand. The novel is read by scrolling; at the end of each section a new header appears, at which point the reader can choose to keep scrolling on into

⁷⁶ Pears, *Arcadia*, 2015, 30.

⁷⁷ Pears, 233.

the next suggested section and follow the same character, but they can also tap arrow icons to switch to a different header, and character, instead. The reader also has the option to select bonus chapters, which are not included in the paper novel; they appear as a popup overlaying the chapter that is currently being read.⁷⁸ The app contains a map of all the sections there are to read, marking which have already been read. The reader can see which path they are taking, and whether they may have missed a section along the way. The app does not impose linearity: it is possible to scroll back and forth through the superstructure and simply choose a section at random. However, the map is visually constructed to display a structure that is ultimately directed toward a single final chapter, just as the scrolling involved in the reading process suggests.

Notably, there is only one first chapter, 'A Landscape', from which all of the branches spread out; similarly, there is only one final chapter, 'Evening Sky', which brings all of the branches back together. Both chapters are extremely short, designed to precisely fill the iPhone screen.⁷⁹ This structure makes the narrative as a whole similar to B.S. Johnson's *The Unfortunates* (1969), where the reader is allowed to read the chapters in any random order, but the first and last chapters are designated as such by the author.⁸⁰ Pears's reader may have the idea that their choices are actively influencing the narrative, that there are other stories they are not reading because of their choices. Yet the structure of the narrative is largely predetermined, and its contents wholly so. Pears has emphasized that he opposes any use of the word 'interactive' to

⁷⁸ These bonus chapters are presented as extracts from notebooks that provide more details about the geographical and social structure of Anterwold.

⁷⁹ The book chapters, in contrast, are much longer, and do not have chapter titles. The book does not open with 'A Landscape' or close with 'Evening Sky'. Each book chapter is divided into sections: the short chapters of the app.

⁸⁰ B. S. Johnson, *The Unfortunates* (1969; repr., London: Picador, 1999).

describe *Arcadia*:⁸¹ his narrative is not interactive; the many-worlds interpretation is not adhered to. There are no different branches that the reader can explore, along which events play out differently. Pears has explained that he introduced the physics into the story in order to make it possible to have two events that are set thousands of years apart seemingly happen simultaneously, in a single narrative.⁸² Interactivity implies that the reader's actions shape the narrative, not only its reading order, but its contents and, crucially, its ending, too.

Conclusion

Fiction that explicitly made use of particular interpretations of quantum physics concepts began appearing less than a decade after the publication of the first papers on these topics. The authors of such works were willing to dedicate significant portions of text to explaining quantum physics to their readers, to allow for the fantastical new stories, or new interpretations of old stories, that the science made possible.

Quantum physics in fiction presents new possibilities for focalization. Identity becomes a questionable concept both in interpretations that claim that the wavefunction collapses and in the many-worlds interpretation. Narratives can present a single focalizer who still gives the reader different points of view through being spread out over eigenstates; they can also present various different focalizers who are, or have once been, one and the same character. The very meaning of the personal pronoun 'I' is questioned when quantum physics is made to influence the narrative.

⁸¹ Iain Pears et al., "TORCH Book at Lunchtime: "Arcadia"" (Oxford, 2 March 2016), <http://torch.ox.ac.uk/book-lunchtime-arcadia>.

⁸² Pears et al. I asked this in the question-and-answer session, which was not filmed.

Introducing quantum physics can change the reader's understanding of the story. Walton's duology is able to make apparently supernatural events hold up in court because they can be explained scientifically.⁸³ The reader will have expectations regarding the development of the plot as the science, its rules, and its consequences are explained. If the collapse of the wavefunction occurs, as in Egan and Walton's works, the reader will know that eventually only one instance of the main character will be left over; if the reader knows the many-worlds interpretation applies, with its constant branching, the reader might expect several instances of the same character to appear and conflict with each other.

The form and structure of a novel can also be influenced by the use of quantum physics. Chapter breaks can function as a marker of a perspective switch, even when this change in perspective does not imply a change in protagonist: Walton uses chapter breaks to switch between different instances of the same character. Quantum physics can also be used to imagine a story that does not have a predetermined reading order, as Borges showed Ts'ui Pen to have attempted in the writing of a narrative that due to its branching does not have an ending. The physical form of the codex limits such a structure, however, as Borges's story itself shows. Digital works of art and hypertext fictions soon turn into intermedial works that are no longer easily classified as literature.

⁸³ Fiction in which supernatural occurrences are brought to court usually involve an opposition between science and the supernatural. See for instance Scott Derrickson, *The Exorcism of Emily Rose* (Sony Pictures, 2005).

Such explorations of new narrative structures could be further developed in new media; however, novelists do not seem to have made as strongly a connection between this new science and new narrative *modes*. The potential for interactive fiction to reflect the worlds of quantum physics does not seem to have been explored fully, or even tentatively, not even now that the internet has made this possibility cheaper and more accessible. Iain Pears has been a ground-breaker in combining new media with mainstream literary fiction to reflect the narrative structures made possible by quantum physics, and one can imagine narratives that incorporate quantum physics further into their structure than has been done until now. One reason might be the logistical difficulties involved in constructing the software behind hypertext fiction. Pears states:

After working my way through three publishers, two designers, four sets of coders and a lot of anguish, I am no longer surprised that few others have done anything about it. I also understand why the NHS database could go five times over budget and not work. What should be a simple task – write story, create software, publish – turns out to be anything but in practice.⁸⁴

The issue of commercialization is connected to these design issues. Creating an interactive work online may be easier, but making that pay in an age of piracy is not. Apps offer a possibility for a payment model, but as Pears shows, these are difficult and expensive to make.

Another reason for the limited success of these hypertext forms might be the unwillingness of the reader to abandon the paper book as a material object, along with the sense of accomplishment that physically finishing a novel and closing the book

⁸⁴ Iain Pears, 'Why You Need an App to Understand My Novel', *The Guardian*, 20 August 2015, sec. Books, <https://www.theguardian.com/books/2015/aug/20/novel-use-for-app-iain-pears-arcadia>.

gives, a feeling that has also slowed down the adoption of e-reader technology.⁸⁵ Interactive fiction, especially the fiction that does not have a single ending, often cannot inform the reader how far along they are in a narrative, meaning that there is no way for the reader to check whether they are making progress and being a 'good' reader. The need for this feeling of accomplishment is reinforced when reading longer narratives. A novel with an open ending can give the reader a sense of dissatisfaction, but at least the reader knows this novel has physically ended now. A novel with neither a narrative nor a physical ending might give the reader so much dissatisfaction that the pleasure that can be gained from the reading experience becomes drastically reduced.

Since literature can present only one narrator at a time – although many texts offer, in sequence, different narrators – the introduction of branched and superposed narratives leads to experiments that push the form to its limits. Although an analysis of other media is beyond the scope of this universe's iteration of this chapter, one might consider how similar questions of identity could be approached in modern media: for instance, the ways in which film and TV might approach superposition by means of a split-screen, or the opportunities for the many-worlds interpretation for video games, which often struggle to create a narrative in which repeated character death is part of the gamer's experience. Literature, on the other hand, can use the conventions of the medium to confront the reader with questions about identity and perspective, showing the immense changes these issues undergo when influenced by ideas from quantum physics.

⁸⁵ Gabriella M. Hancock et al., 'Is E-Reader Technology Killing or Kindling the Reading Experience?', *Ergonomics in Design* 24, no. 1 (1 January 2016): 25–30, <https://doi.org/10.1177/1064804615611269>.

Conclusion

Richard Feynman's claim that 'nobody understands quantum mechanics' seems to have been perceived as an inspiration and a challenge, rather than a deterrent.¹ From the start of the twentieth century onwards, quantum physics has been considered and communicated as strange, counterintuitive, and impossible to understand. Yet at the same time, works aimed at everyone from toddlers to physics graduates have attempted to explain this science in a manner appropriate to their respective audiences. Meanwhile, even those who do not seek to learn more about quantum physics through popular expositions are increasingly likely to encounter it in various guises in fiction: both in science fiction, in which the reader expects an encounter with advanced science, and in works that do not raise such expectations, including children's fiction.

In this thesis, I have sought to explore this plurality of quantum physics narratives and the way they have mutually shaped both the public perception of quantum physics and the science itself. My investigation led me to draw from three fields that overlap on the topic at hand, but which largely function as separate research areas in academia: science fiction, science communication, and literature and science. My research has shown that a full comprehension of the stories of quantum physics cannot be achieved without taking all of these fields into account; bringing them together has highlighted the relative neglect of works for children in all three areas. I have shown, however, that engagement with children's fiction and popular science is vital to under-

¹ Richard P. Feynman, *The Character of Physical Law* (1965; repr., London: Penguin Books, 1992), 129.

standing the extent to which disciplinary conflicts and cutting-edge science is communicated to various audiences. The discourses in which individual scientists participated have in several cases crossed these genre boundaries: scientists who have been active contributors to the field later became influential authors of popular science for adults or children, or both. Popular quantum physics books and fiction that makes use of quantum physics both build on the same sets of metaphors, tropes, and narrative traditions. Applying the techniques of literary criticism and narratology not only to literary works, but also to nonfiction, has revealed what is left out of the narratives for non-experts, and has revealed that popular science, fiction, and science itself mutually interact to shape the entire range of narratives. The thesis shows that not only does science shape the stories, these stories in turn shape the science, too: public engagement with, rather than public understanding of, quantum physics and its various interpretations has been a priority for scientists working in contested fields.

Paradoxically, science is seen as authoritative, yet it is characterized by constant supersession of older theories by newer ones, usually after a period of conflict. Quantum physics at the moment consists of very many different interpretations, all of which are currently untestable, each with their own adherents and opponents. In this thesis I have focused on three of these interpretations: the Copenhagen interpretation, which is usually the only one taught in university-level physics books and courses; the many-worlds interpretation, with its strong narrative appeal; and the conscious collapse interpretation, which is characterized by being strongly rejected by many scientists, yet embraced by those who see it as a verification of mysticist beliefs. The thesis has highlighted the centrality of the conflict narrative to stories that cover cutting-edge science about which a consensus has not yet been achieved, regardless of the story's genre or

intended audience. A conflict that has for the largest part been played out in scientific journals can be used as a major selling point for a work of popular science, and may even surface in a children's book. When popularizing quantum physics, authors shape their audience's view of what quantum physics is by selectively focusing on the interpretation they support, whilst silently omitting or even openly speaking out against other interpretations. Fiction authors, meanwhile, can use the unresolved state of quantum physics as the basis for a narrative of discovery, in which a scientist finds out which of the interpretations is true, and immediately extrapolates the consequences of this revelation to applications that change the fictional world.

The widespread popularity of the many-worlds interpretation permeates all three fields of investigation. The thesis has shown that the many-worlds and the conscious collapse interpretations became the most widely communicated stories, because these two interpretations fit into a mould of existing narratives, whereas these two are considered marginal within the scientific community. The many-worlds interpretation is now the most commonly popularized one, in fictional and nonfictional works alike, whereas the Copenhagen interpretation is the one most often taught at university level. However, it is not until one brings in works for children that one can observe a curious discrepancy: popularizations of quantum physics for children do not favour the many-worlds interpretation. Instead, these works focus on explaining the essence of quantum physics that all interpretations share and struggle with in their own ways: the double-split experiment, wave-particle duality, and the role of probability. These elements baffle adults, physicists or not, but are more easily communicated to children who have not yet learned that physics was normally supposed to function under more deterministic rules.

In recent decades, quantum physics has proven to withstand tenaciously pressure on its most counterintuitive concepts: quantum teleportation at the photon level was first achieved in 2011, and entanglement, Einstein's 'spooky action at a distance', is being proven at increasingly large distances.² The latter finding in particular has garnered interest in quantum physics among non-experts due to the possibilities entanglement presents for cybersecurity: entanglement can be used to encrypt messages that cannot be decoded by a third party.³ However, the underlying explanations, and the unification of quantum theory with relativity, continue to be elusive. It is therefore difficult to predict where either quantum physics itself, or stories about quantum physics, will go from here. New interpretations continue to be coined, and popularized, the most recent to undergo such treatment being Quantum Bayesianism or QBism.⁴ If the many-worlds interpretation were to be disproved soon, the many narratives that rely on it as an attractive narrative trope will be instantly outdated, in the same way in which in the mid-twentieth century authors had to regretfully abandon Schiaparelli's 1877 conjectures regarding *canali* on Mars. The potential existence of these features, and an awkward mistranslation of 'canali' as 'canals' rather than 'channels', had led to half a century of exciting conjectures about life on the red planet: whereas 'channels'

² Noriyuki Lee et al., 'Teleportation of Nonclassical Wave Packets of Light', *Science* 332, no. 6027 (15 April 2011): 330–33, <https://doi.org/10.1126/science.1201034>; Hensen et al., 'Loophole-Free Bell Inequality Violation Using Electron Spins Separated by 1.3 Kilometres'.

³ Hensen et al., 'Loophole-Free Bell Inequality Violation Using Electron Spins Separated by 1.3 Kilometres', p. 682.

⁴ von Baeyer, *QBism*.

can be created by natural processes, 'canals' are artificially created.⁵ This thesis, investigating the communication of cutting-edge science, faced the very small chance that most of its subjects of investigation could be classified as outdated during its writing – a potential that the authors of both the fiction and the popular works also faced. I have shown how meanwhile, in the absence of scientific consensus, the authors of popular science and fiction alike fill the gaps in scientific knowledge either with their own preferences or with the most appealing story, leading to a popular understanding of science that is shaped for a large part by the most eloquent and captivating narratives.

I have not aimed to present a complete analysis of all contemporary stories of quantum physics. In order to construct a more complete picture of the various ways in which these stories are told, a further analysis of these tropes in other media would prove productive. Whereas I have focused on book-length written works, an analysis of shorter works – science journalism and short stories – would highlight the priorities of the author when there is little room for a full explanation or infodump. The author could choose to exclude an explanation of the conflicting interpretations, as popularizations for children do, or in fact find that the lack of a definitive interpretation can be used to captivate the reader from the opening paragraph onwards.

The thesis has investigated the potential of literary tropes to depict, reflect, and respond to concepts from quantum physics. A comparison with other media, especially visual media, would bring out the effects of literary versus visual tropes in communicating quantum physics. Film, TV, and games are able to use the visual aspects of their

⁵ Brian Dunbar, 'The "Canali" and the First Martians', NASA, 13 April 2009, https://www.nasa.gov/audience/forstudents/postsecondary/features/F_Canali_and_First_Martians.html; 'Canals of Mars', Encyclopædia Britannica, Britannica Academic, 13 August 2017, <http://academic.eb.com/levels/collegiate/article/canals-of-Mars/51084>.

respective media to construct new explanatory metaphors and analogies, and integrate the science in their narratives in ways that the written text is unable to do. An analysis of film and TV narratives that communicate quantum physics in fiction and nonfiction would include the films *Los Cronocrímenes* (2007), *Source Code* (2011), *Coherence* (2013), and, controversially, the mysticist *What the Bleep do we Know!?* (2004); notable TV series include *Doctor Who* (1963-1989 and 2005-present), *Rick and Morty* (2013-present) and the BBC's two-episode popular science series *The Secrets of Quantum Physics* (2014). Even the narratives analysed in this thesis might soon be submitted to visual analysis. No fewer than three film and TV adaptations of novels discussed here have been planned for 2018: the BBC adaptation of *His Dark Materials*, a film adaptation of *A Wrinkle in Time* starring Oprah Winfrey as Mrs Which, and a film adaptation of *Dark Matter*. That year will also see the release of the film *Quantum Theory*, starring two female quantum physicists.

The interactivity and immersion that is required to play computer games can be used for the construction of new forms of quantum physics narratives, in particular those that simulate or emulate the kinds of narratives explored in Chapter 6. At the same time, quantum physics can be used to address problems that have long plagued video games. Games such as *Life is Strange* (2015) and *BioShock Infinite* (2013) explore character death through explicitly introducing quantum physics concepts such as branching universes. The potential for repetition after failure – a narrative game is the only art form the consumer has to be skilled at in order to access the whole narrative – can be used to make sure the gamer has gained a complete understanding of the concepts before they are allowed to proceed.

The thesis has revealed how reading across different types of texts highlights the mutual influences between a science and its narratives. By looking at different age groups, it becomes particularly noticeable how authors deal with a state of indeterminacy in science, when several empirically equivalent narratives coexist. A story of quantum physics never stands by itself, but is informed by scientific and narrative traditions alike, and is itself part of a conversation that shapes the science and the way it is perceived by its various publics.

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