'If You Can't Explain It to a Six-Year-Old…': Communicating Quantum Physics to Children

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Introduction

Children's popularizations of science, since their conception in the eighteenth century (Topham, 2007, p. 143), have been based on practical and tangible elements: they generally rely on recognizable metaphors and often contain experiments which children can perform themselves. However, children's books that cover quantum physics rely on fiction, rather than on experiments, to keep their readers entertained while educating them about this complicated topic. The children's books I have been able to identify that discuss quantum mechanics are written as fictional stories: Russell Stannard's *Uncle Albert & the Quantum Quest* (1994), which is the third instalment in Stannard's *Uncle Albert* series (1989-1998), and the *George* series written by Lucy and Stephen Hawking (2007-2016). These books are aimed at children between ages 8-12: the readers will not have encountered the topic in a school setting yet. The fiction these stories present is hugely intertextual, relying on stories the reader will have encountered before.

Gilmore, Stannard, and Alice in Wonderland

In 1994, two very similar popularizations of quantum physics were published almost simultaneously, and both relied on an Alice in Wonderland setting to convey their topics. Robert Gilmore's *Alice in Quantumland: An Allegory of Quantum Physics* is set in the late twentieth century – Alice falls into the TV, rather than down rabbit hole – but all the well-known elements of *Alice in Wonderland* and *Through the Looking-Glass* are included as playful references. Whereas Gilmore's work is written for adults, Russell Stannard's *Uncle Albert and the Quantum Quest*, on the other hand, is written for children aged '10+ years and more'; it takes a more irreverent approach to the Alice in Wonderland trope, although it still relies on the reader's familiarity with the story.

The work is part of a series which Stannard began in 1989, which focuses on a young girl, Gedanken – her name means 'thought' as in 'thought experiment' – and her uncle, Albert, a revered physicist. Uncle Albert, of course, is Albert Einstein, who is famous for his thought experiments. In the *Uncle Albert* series, he can make his thought experiments come to life: Gedanken can crawl into one of his thought bubbles and enact the experiment from there. In this book, Uncle Albert asks her to find out what atoms are made of, leading her to observe that they have both particle- and wavelike properties at very small scales. However, initially she is extremely unhappy, as she climbs into her uncle Albert's thoughts, to find that the thought experiment she is part of in this book is based on *Alice in Wonderland*:

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> ‘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. (Stannard, 1994, p. 7)

Although Gedanken finds the reference to the *Alice* books dull and old-fashioned, she comes to appreciate the quantum mechanical version: the White Rabbit is the Chief Scientist of the Queen of Hearts, who is making her executioner chop molecules into smaller bits. The Wonderland setting helps Gedanken: the bottle labelled ‘Drink Me’ makes her so small that she can look at the inside of an atom. The White Rabbit helps her perform the double-slit experiment, which shows diffraction properties, with light; the Cheshire Cat helps her perform the same experiment with electrons.

As these two examples show, both popularizations for adults and those for children have made use of an Alice in Wonderland metaphor to communicate concepts in physics. Carroll’s creations have also permeated physics itself, to such an extent that he has provided many of the most conveniently available stock metaphors within physics and physics outreach. In 1976, David Mermin embarked on “a long-running campaign to see if I could make the silly word ‘boojum’ an internationally accepted technical term.” (Mermin, 1999). Carroll’s nonsense word from *The Hunting of the Snark* indeed became accepted as term for geometric pattern in superfluidity. Alice is also a textbook character: when speaking of multiple observers, the usual approach in physics – and cryptography – is to use the placeholder names Alice and Bob, rather than naming them A and B. Although there is no direct connection to Carroll’s Alice, this use has made it one of the most famous girls’ names in physics. However, for this essay the particular relevance of the Alice in Wonderland trope is the fact that it can be used in children’s books, because it is itself taken from a very widely known children’s book.

The familiarity with both the name in physics and the story to the general public may have influenced the name of one of the CERN experiments, ALICE: A Large Ion Collider Experiment. The logo of the experiment has a little blonde girl in a blue dress standing with her back to us on the E. The connection to Lewis Carroll’s books is made directly in the ‘Children’s Corner’ of the ALICE website: a comic is available for download there which explains the ALICE 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. Notably, although the ALICE logo shows Tenniel’s/Disney’s Alice, the Alice in the comic book is modernised: she has short brown hair, trousers, and a crop top (Boixader, 2004).

In using the *Alice* books as a stock fantasy setting for science books, Tenniel’s original illustrations are as important as Carroll’s story. I have yet to encounter a popular science book for children that is not illustrated. Misleading as illustrations 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 mechanics, however, is difficult to illustrate due to the inherent unobservability of many processes in this field. Stannard resolved this issue through using a combination of anthropomorphization and reference to *Alice in Wonderland*, whose illustrations as familiar as its storyline.

Choosing *Alice in Wonderland* as a basis for a scientific fantasy is not an unexpected approach. Not only is it a story which nearly all English-speaking readers of ‘10+ years and more’ will be familiar with, through having read it, watched its film adaptations, or having been exposed to Tenniel’s images, the work itself also engages with science at a fundamental level. Even those readers who would agree with Gedanken that “Nobody reads that old fuddy-duddy stuff these days” (Stannard, 1994, p. 33) would recognise the basic tropes from the story by the time they have reached the age the books discussed in this chapter are aimed at. As the title of Melanie Keene’s work on nineteenth-century popularization, *Science in Wonderland*, suggests, the science component in this fantasy was recognised 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 (Keene, 2015, p. 105).

In his day-to-day life as a mathematician, Charles Dodgson fiercely defended the idea of a Euclidean world when new mathematics started questioning it. However, as Gillian Beer points out, under his pen name of Lewis Carroll, he 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 (Beer, 2011b). Such a world, in which even the most surprising and unbelievable new ideas of physics are possible, lends itself eminently to adoption by popularizers who write for children.

Another reason why *Alice in Wonderland* works so well as an analogy for quantum mechanics is because of the way in which Carroll’s books engage with nonsense. As in many regular popularizations, knowledge in the *Alice* books is exchanged via dialogue (Beer, 2011a, p. xxxii), but nonsense prevails. Quantum mechanics, 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.” (Gilmore, 1995, p. 48). Stannard points out that this is one of the reasons why advanced modern physics can and should be communicated to children:

> 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 (Stannard, 2001, p. 31).

The way in which *Alice in Wonderland* engages with nonsense enables the young reader, who is implied to be still flexible enough to accept an impossible-sounding story and follow it through to the end, 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 (Carroll & Tenniel, 2001, p. xxiii).

The Hawkings and George

The second book series I will discuss is the one which fiction author Lucy Hawking has co-authored with her father, Stephen Hawking, about a young boy named George: *George’s Secret Key to the Universe* (2007), *George’s Cosmic Treasure Hunt* (2009), *George and the Big Bang* (2011), *George and the Unbreakable Code* (2014) and *George and the Blue Moon* (2016). In the first instalment, *George’s Secret Key to the Universe*, George, the son of two strict environmentalist parents, discovers that he has new neighbours: the world-famous astrophysicist Eric, clearly modelled on Stephen Hawking, and his daughter, Annie. Together, they go on adventures throughout the universe aided by Eric's computer Cosmos, who is sentient and can open portals to distant parts of the universe. The Hawkings thus fit their books into a long-standing tradition of rocket ship adventure stories for children, which harks back to the golden age of science fiction, the early twentieth century. Not coincidentally, COSMOS, the UK National Cosmology Supercomputer, is a real supercomputer used at Cambridge. Stephen Hawking is a primary investigator on this project.

The storyline of each book contains many references to specific scientific content, which is further explained in separate informative sections. The fact that these sections are separate 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 some facts sometime after having finished the book can easily access these sections.

In a BBC interview given before the publication of the first book, Lucy Hawking claimed that it "would be aimed at people like her own eight-year-old son." ("Hawking to write children's book," 2006). However, both the publisher and reviews describe that age as the very minimum, and claim that the book is aimed at children age 8-12 (Berman, 2007; "George's Secret Key to the Universe | Book by Stephen Hawking, Lucy Hawking, Garry Parsons," 2016, "George's Secret Key to the Universe: Kirkus Review," 2007). Science popularizer John Gribbin gives one possible explanation for this discrepancy in his review: the content of the stand-alone informative boxes is "pitched at a distinctly higher level of readership than the story itself" (Gribbin, 2007). 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 *George and the Blue Moon* shows ("NEW books for 8 to 12 year olds in March - World Book Day," 2016). The books therefore seem to be addressing several different audiences: younger children will enjoy the storyline from the first book onwards and will enjoy reading about older characters as the books progress; older children will enjoy the informational sections and the later books as George and Annie grow up; and adult readers will enjoy reflecting on the manner in which cutting-edge science is communicated in a very simple manner, allowing parent and child to discuss the latest science together.

The *George* series is notable for the inclusion of Stephen Hawking's own research: as the front cover of *George's Secret Key to the Universe* announces, the book "Includes the LATEST IDEAS about BLACK HOLES!" (Hawking, Hawking, & Galfard, 2007, front cover). Aside from the grey informational boxes, in later *George* books, contributions of several well-known scientists on the "Latest Scientific Theories!" are also added to the books in separate chapters. Here another audience might have been intended: parents or older readers familiar with these scientists can easily look up these sections without having to read the entire children's adventure story. In these chapters, Hawking himself initially continues to write under the name Eric, 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'." (Gribbin, 2007). In *George's Cosmic Treasure Hunt*, Hawking still uses his fictional alter ego, Eric, instead of his own, for these essays; yet in *George and the Big Bang*, his essay is signed "Dr Stephen Hawking"; and in the last two books, it is signed "Professor Stephen Hawking" (Hawking & Hawking, 2014, table of contents; Hawking, Hawking, & Parsons, 2011, table of contents).

Popularizations are not necessarily written to communicate the author's own scientific findings. 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.” (Myers, 1985, p. 42). In works for children, such a position 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 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.

In *George and the Secret Key to the Universe*, Hawking radiation is explained – a quantum mechanical phenomenon that is usually not taught below university level. Rather than anthropomorphising such an abstract phenomenon, as Stannard and Gilmore have done, George encounters it in a different kind of unrealistic setting: a science fiction story. Eric, who has been swallowed by a black hole, is slowly radiated out again, and Cosmos is able to assemble him from these individual particles. Eric emerges again from the computer, all his memories intact; the only error Cosmos made is that Eric is now wearing the wrong glasses.

This content drags the George books into a much wider debate: the black hole information-loss paradox. Different interpretations of this paradox by Hawking and Stanford physicist Leonard Susskind led to what the latter in 2008 called ‘the Black Hole War’ (Susskind, 2009). Interestingly enough, George’s adventure assumes the Susskind interpretation of the black hole information paradox: information is *not* irretrievably lost in a black hole. This clearly shows that Hawking admits to having lost the Black Hole War and is now on Susskind’s side. Although Hawking had publicly admitted that information does leak out of black holes at a press conference in 2004, *George and the Secret Key to the Universe* was Hawking’s first popular work since this admission In fact, as Susskind points out, Hawking officially conceded to having lost bets with John Preskill and Don Page on this topic in 2007 (Susskind, 2009, p. 444), the same year in which the first *George* book was published. The children’s books are thus reflecting the outcomes of cutting-edge scientific disputes even if the disputes themselves are not taken up in these books.

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 (Bell, 2008, pp. 62–63). Elsewhere, I have shown that including experiments in science books for children enhances the readers’ engagement as they are able to feel in control. 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 (Dihal, 2014).

Unfortunately, there are no quantum mechanics experiments which can be performed by a young reader alone, that I know of: 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 discuss science that is too abstract to manually work with. Therefore, the fictional component of the stories becomes more important as the practical execution becomes impossible. Russell Stannard in particular has solved this issue through focusing on thought experiments, and centring his works around these rather than on 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 (Stannard, 1994, p. 41). His book does have an interactive element, but this too is theoretical: the story ends with a quiz, which Gedanken has ostensibly created for her uncle to make clear to him how educational computers can be. The answers are included at the end of the quiz (Stannard, 1994, pp. 131–140). By focusing entirely on thought experiments, he also makes clear to the reader how important these are in the development of modern theories of physics.

In both cases, 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 the protagonists of the book find themselves in: in a similar manner, the readers of *Alice in Wonderland* will know that they will not be able to repeat Alice's adventures, because of their clearly fictional nature and the fact that at the end of the book Alice wakes up from a dream. Russell Stannard reminds his readers that his books can also be enjoyed by children as pure science fiction stories: "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 emphasises that modern physics, through the special fascination it stirs in the reader, is easily adaptable to a story format, more so than "more mundane physics—of the National Curriculum type" (Stannard, 2001, p. 32). The reader is encouraged to observe and enjoy the story, rather than participate in it.

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