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Bringing Science into Fiction

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Writing novels about science breaks the contract between reader and author. People like stories, not lectures.

Alan Lightman

Abstract: Science and its predecessor, alchemy, have been topics of fiction in the West for over five centuries but until late last century novelists, with few exceptions, condemned science and scientists on social and moral grounds. However, since the 1990s, science has acquired a more benign and humane image, associated with combatting deadly viruses, saving endangered species and communicating the urgency of dealing with climate change. Novelists, too, are increasingly intent on authenticity in presenting scientific research and the motives and moral dilemmas of scientists. Such science novels risk being overloaded with scientific facts and explanations, so the craft of the writer involves integrating the necessary scientific information without damaging the artistic integrity of the work. This paper explores, through interviews with authors and in-depth reading of texts, how the following writers accommodated the science component within the life-world of their narrative and took steps to avoid an ‘information dump’: Rebecca Goldstein (*The Mind-Body Problem* and *Properties of Light*), William Boyd (*Brazzaville Beach*), Simon Mawer (*Mendel’s Dwarf*), Susan Gaines (*Carbon Dreams*), Clare Dudman (*Wegener’s Jigsaw*), Richard Powers (*The Echo Maker*), Barbara Kingsolver (*Flight Behavior*), and Pippa Goldschmidt (*The Falling Sky*).

1 Introduction

Science and its predecessor, alchemy, have provided topics for fiction in the West for over five centuries but until the 1990s they and their practitioners were, with

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remarkably few exceptions, condemned by writers on moral grounds. Alchemy was decried as a hoax, played upon the greedy and the gullible; the seventeenth-century virtuosi, with their vast, expensive collections, were portrayed as foolish and credulous victims of fraudsters purveying useless curiosities and fakes. The English Romantic writers, led by William Blake, condemned science as arrogant and dehumanising, stifling emotions, imagination and creativity in the cause of materialism and rationalism. In the twentieth century, the escalation of nuclear weapons led to an identification of science with military exploitation. Scientists were portrayed as being either morally distressed at losing control over the deployment of their research (Balchin 1943; 1949), or so elated by the physical power they had unleashed as to be unconcerned about humanitarian consequences (Haynes 1994, 246–263; 278–294).

The fictional stereotypes thus generated and reinforced through the centuries of the scientist as mad, bad, obsessive, impersonal or foolish, were to remain current, almost universal, until the end of the twentieth century in both fiction and film in a way that is true of no other genre. They are the outstanding exception to Moretti's evolutionary model of literary history, which posits changes and divergences in the genre of British novels over time, analogous to the evolution of organisms in Darwin's 'Tree of Life' diagram (Moretti 2005; Darwin 2009, 630–631).

A temporary exception to this negative imagery was provided by Jules Verne's *Voyages Extraordinaires* and by the *Scientific Romances* and novels of H.G. Wells. By linking science to technological and engineering inventions, these writers created a new image of the scientist as a fearless adventurer, transcending physical boundaries. Both authors were skilled in embedding science in their narratives and, in Wells's case, in tracing the social consequences of his thought experiments. Wells also produced the forerunner of the science novel: *Ann Veronica* and *Tono-Bungay* depict the first realistic characters involved in science research. However, these positive readings were soon eclipsed by the involvement of scientists in the events of World War II.

2 The Science Novel

During the 1990s, science began to achieve a more humane and realistic image. Scientists were depicted as eliminating deadly viruses, fighting to save endangered species, the environment and the planet, and communicating the urgency of dealing with climate change. Simultaneously, there has been an increased number of writers with training in the sciences and a commitment to present with

greater accuracy and attention to detail the specific ideas and processes involved in scientific research. Novelists have focused particularly on the motives of their scientist characters, the unexpected consequences and moral dilemmas their research poses, and what it ‘feels like’ to ‘do science.’ Importantly, the ‘science experience’ is presented as integrated into a psycho-social matrix and thus accessible to the non-specialist reader.

In effect, then, the science novel is essentially a complex construction, drawing on three major fields of philosophy as applied to science: epistemology (the nature and scope of the scientific knowledge that is sought or acquired by the characters); ethics (the moral dilemmas concerning right and wrong actions, usually in relation to the social and environmental implications of research); and phenomenology (the conscious experience of the scientist characters while ‘doing science’ and their reflections on that experience).

The unique quality of the science novel, compared with other forms of the genre, lies in its ability to convey the felt experience of scientific research. Whether homodiegetic narratives (like *Wegener’s Jigsaw*, *The Mind-Body Problem*, sections of *Properties of Light*, *Brazzaville Beach* and *Mendel’s Dwarf*) or heterodiegetic narratives (*Flight Behavior*, *Carbon Dreams*, *The Echo Maker* and parts of *Mendel’s Dwarf*), all the novels selected for this study attempt to convey the experience of involvement in some branch of science: the elation of discovery tempered by the frustrations, conflicts, doubts and ethical minefields that are inherent in the research process, and the not infrequent sense of failure and subsequent depression, such as we see in Noam Himmel in *The Mind-Body Problem* and John Clearwater in *Brazzaville Beach* when their creativity in math fails, or even madness like that of Samuel Mallach in *Properties of Light* when his theory is ignored.

Like historical novelists, writers of science novels have two implicit contracts: to represent credibly the discipline they write about and to retain the interest of their readers in the narrative. At times these have seemed incompatible. Novelist Michael Brooks recalls, “I was careful to remember what physicist and novelist Alan Lightman said about not writing novels about science because it breaks the contract between reader and author. People like stories, not lectures” (Brooks 2007, 52). Ironically, Lightman himself has written a highly successful science novel, *Einstein’s Dreams* (2004).

The science novelist is faced with four potential pitfalls: the science may not be credible; the scientific discourse may not be easily translated into the discourse of literature; the science content may be too dense, destroying the suspension of disbelief in the narrative and the artistic integrity of the work; the novel may become overly didactic or propagandist concerning some particular ethical issue related to the science.

This paper explores, through interviews with the authors and in-depth reading of the texts, how a selection of writers, some of whom had a science background, others not, accommodated the science component within the life-world of their narrative and took steps to avoid an ‘information dump.’

3 Why do Authors Write Science Novels?

For many science novelists the initial stimulus was an interest in either a scientific concept or experience, or a significant figure in the history of science – Alexander von Humboldt, Friedrich Gauss, Gregor Mendel, Alfred Wegener, Albert Einstein, David Bohm.¹ Such historical figures, especially if, like Wegener, they conveniently leave papers, letters or diaries, make the novelist’s task easier. The events, the science, the characters and even the authentic ‘voice’ are given. Simon Mawer says, “I definitely thought of talking about Mendel first. He’s in all the textbooks, rather inaccurately reported, and I wanted to set the record right” (Mawer 2014). But he was also concerned with a moral issue – the politicisation of genetics through eugenics, taken to its extreme by the Nazis, and “the new eugenics, *our* eugenics, governed only by the laws of the marketplace” (Mawer 1999a, 273, emphasis in the original).

Goldstein’s inspiration for *Properties of Light* was her knowledge of the discussions about quantum mechanics occurring between her first husband and fellow mathematicians, in particular the reclusive figure of David Bohm: “I was moved by David Bohm. I was moved by his story” (Goldstein 2014).

For Dudman it was initially a long-term interest in Continental Drift, “but this soon developed into a fascination with the figure of Alfred Wegener because I discovered that he was a record-breaking balloonist as well as a revolutionary scientist, also a polar explorer” (Dudman 2014).

Kingsolver’s *Flight Behavior* was propelled by her sense of responsibility to write about “the particular culture war” that was raging over climate change, and to investigate the psycho-social reasons for opposing views about freakish weather patterns: evidence blindness versus evidence-based arguments (Walsh 2012, n. pag.):

¹ These historical figures feature in Daniel Kehlmann’s *Measuring the World* (2007) (von Humboldt and Gauss), Simon Mawer’s *Mendel’s Dwarf* (1999a), Clare Dudman’s *Wegener’s Jigsaw* (2003), Alan Lightman’s *Einstein’s Dreams* (2004) and Rebecca Goldstein’s *Properties of Light* (2001).

I wanted to talk a little bit about environmentalism and class, which is just really not talked about in this country. [...] To have sympathy for the people who don't really have the options to think so much about the future and what our obligation is to them and what our obligation is to the people who aren't born yet. (Wood 2012, n. pag.)

However, the immediate image that crystallised this intention into a novel was non-rational:

The freak biological event that drives this whole story just came to me in a vision. I woke up one morning with that sight behind my eyes, behind my eyelids. There it was. I pictured that valley of flame in an Appalachian forested mountainside and I thought, 'Wow, there's a novel right there.' Half the people would see it as a miracle organized by God and the other people would see it as horrifying proof of global warming. And there began the novel. (Walsh 2012, n. pag.)

The imagined picture was derived partly from Kingsolver's prior knowledge, as a biologist, of the migratory swarm of monarch butterflies, but transposed, in her subconscious, to a very different location, far to the north of their usual settling place. This image is echoed in the heroine Dellarobia Turnbow's epiphanic vision of the forested valley afire with an orange blaze, a sight that she only later realises is due to the millions of monarch butterflies settled on the tree branches.

For Susan Gaines the starting point for *Carbon Dreams* was the intention to convey the experience of science research:

I wanted to write about scientific creativity and intuition. I wanted to write about science as a *process*, not as a collection of facts. I wanted to write about uncertainty. And I wanted to write about a scientist as a person who was deeply curious about nature, someone with a sense of awe about the world, for whom that was almost a spiritual connection. (Gaines 2014, emphasis in the original)

Goldschmidt's motivation was also phenomenological:

I wanted to write a novel exploring the process of doing astronomy, what it actually felt like from the inside – the complexities of the scientific process, which I thought were never properly reported in formal academic papers, or even in popular science. (Goldschmidt 2014)

The *agon* (Colaguori 2011) into which her character Jeannette is plunged arises from her observation of a phenomenon that appears to overthrow the prevailing paradigm, the Big Bang Theory. If vindicated, such a discovery could launch Jeannette's career, but it evokes anger, disbelief and jealousy from her colleagues and an anxious sadness in herself at the potential destruction of a theory that gives meaning and structure to the universe and, by extension, to her own fragmented life:

I wanted to get across to the reader Jeannette's ambivalence about attacking a theory that she, as much as any other astronomer, loves. And that was how I felt about it too, and I still do. It's a wonderful, wonderful theory. (Goldschmidt 2014)

By contrast, Richard Powers's *The Echo Maker* is a complex neuro-narrative that interrogates conventional notions of cognition and the self by investigating cases where these have been compromised and then showing that they are located on a continuum with so-called 'normal' people. He writes:

This was my aim in *The Echo Maker*: to put forward, at the same time, a glimpse of the solid, continuous, stable, perfect story we try to fashion about the world and about ourselves, while at the same time to lift the rug and glimpse the amorphous, improvised, messy, crack-strewn, gaping thing underneath all that narration. (Champion 2006, n. pag.)

Novelists may also be drawn to create scientist characters because they believe that science is a heroic pursuit. Rebecca Goldstein says:

The reason I'm so often drawn to mathematicians or physicists is that one of the great themes in literature is the hero, someone who takes on a larger-than-life quest, and what is larger-than-life but nature? So they are the kind of heroes of our day. There is also the beauty of it and how ruled by beauty scientists are. This is scientific, mathematical, theoretical beauty, and there's a very strong motivation for me to try and get that across. (Goldstein 2014)

In *The Mind-Body Problem*, Noam Himmel expresses this in relation to mathematics, which for him is the supreme, integrating experience: "The truth of science, the beauty of art. Math exceeds all" (Goldstein 1993, 93). In describing his discovery of a new set of numbers, Noam envisages them as Platonic Forms: "Numbers so big. A beautiful vast infinity of them, waiting there in the great solemn silence, waiting there for me" (Goldstein 1993, 46). *Properties of Light*, too, is shot through with the poetic equivalents of concepts in physics. Poetry provides the metaphors that express scientific truth. "Nonlocality is merely the expression of quantum entanglement," says Dana and Mallach prompts her to quote Francis Thompson's poetic correlative: "All things [...] / To each other linkèd are. Thou canst not stir a flower / Without troubling of a star" (Thompson 1913, stanza XXI). For Justin Childs, the intermittent autodiegetic narrator, math is "a purifying fire"; for Mallach and his daughter Dana their physics is the intuition of "the gnosis of the psi" and together they have "shaken loose a star from the tree of stars" (Goldstein 2001, 100).

4 Character

Significant as these originating concepts are, the essential element of the novel is character. The science novel relies heavily on scientist figures, not only to capture

and sustain the interest of the reader and to provide continuity of plot and structure, but also to expound, enact or respond to scientific ideas and to convey the realistic experience of ‘doing’ science.

While the function of expounding science is also a feature of science fiction, the characters of this genre are rarely developed beyond noble or evil stereotypes, subsidiary to the plot or exposition, without thoughts or feelings as individuals. Even H.G. Wells, a forerunner of science novelists, conceded that his characters were subsidiary to his sociological purpose of ventilating science-related issues: “I found I had to abandon questions of individuation. [...] I had very many things to say. [...] I began therefore to make my characters indulge in impossibly explicit monologues and duologues” (Wells 1934, 497–498). Such a procedure was anti-thetical to Wells’s contemporary Henry James, for whom character was to be presented discursively and in great detail as an end in itself, and an acrimonious and unresolvable debate ensued between the two (Haynes 1980, 243–247).

The science novelists discussed here are located somewhere between these two extremes. Their characters function primarily as wisdom seekers, exemplifying and clarifying some scientific issue, but they are also given at least a minimal life beyond their science because, without characters capable of sustaining interest and surprise, narrative is reduced to didacticism. Nevertheless, few of the characters in science novels are developed in the psychological depth we are accustomed to expect in mainstream literature. During interviews, most of the selected novelists acknowledged that characters came late in the formulation of their novels, certainly later than the original ideological concept which remained their central focus.

Describing the evolution of *The Falling Sky*, Goldschmidt admitted:

The theme of the novel was going to be about an astronomer wrestling with the process of doing astronomy. But I didn’t have any idea what the characters would be or what the plot would be. [...] So Jeannette is a means to tell the story of what it is like to be an astronomer and also to engage us with the Big Bang Theory as an example of the disputes in science and how scientists deal with them. (Goldschmidt 2014)

Mawer had long been fascinated with Gregor Mendel and the science of genetics, but the main character Ben was a later creation:

I was looking to explore that story [of Mendel] first. And then as I began to deal with it, my narrator (because it was going to be a work of fiction, not non-fiction) had to take on a personality and I thought fairly early on, but certainly secondary to my Mendel story, that he needs to have some fairly disastrous genetic problem. (Mawer 2014)

For Goldstein also, characters are secondary to plot in the creative process. “So many different things will suggest a story, a plot. And then come the characters

and the setting, and lastly the theme. Often the science comes in later” (Goldstein 2014). For the characters of *Properties of Light* science is a deeply intuitive and physical experience. Justin reports, “[Mallach] told me how it was that he felt the science within himself, in the sensations of his own body. He told me how he could feel the hidden motions of matter as displacements in his own muscles” (Goldstein 2001, 99).

Goldstein’s scientists are all eccentrics. Noam Himmel is the brilliant but absent-minded professor who forgets to eat or sleep unless reminded and who, left alone, loses his whereabouts. Mallach, whose seminal paper on quantum mechanics was ignored by his peers, has been driven mad, Justin thinks, by anger and resentment. “What, after all, had driven him so near the icy edge of madness (and was he not still mad?) but the enmassed indifference of his peers?” (Goldstein 2001, 52).

Similarly, Gaines says of the development of *Carbon Dreams*, “I had been writing and thinking about humans’ relationship to their natural environment. I wanted to bring a scientist’s sensibility to that relationship. I started with Tina, and I was very much aware that being a scientist *defined* her” (Gaines 2014, emphasis in the original). Intent on stressing the importance of speculation in the science process, Gaines introduces this from the start through her female researcher. After attending a seminar on the origin of life Tina emerges thinking, “that was pretty much how it always was with origin-of-life research. It was *all* speculation, most of it pretty wild” (Gaines 2001, 4, emphasis in the original). Speculation eventually becomes a target of climate change deniers, who insist that global warming predictions are merely hypothetical and unprovable. Through Tina, Gaines argues that climate change research is necessarily speculative: there can be no definitive, observable evidence ahead of time but speculation is nevertheless legitimate.

A significant exception to the secondary role of character is Dudman’s Alfred Wegener. She says:

For me ‘character’ is the most important feature of any novel – regardless of topic or genre. I think that once that is in place, everything else will follow. The character provides the interest and entertainment, and allows the reader to empathize and imagine how it would be to ‘do’ science. The business of communicating science, the social and environmental implications and the motivations are integral parts of a fully rounded ‘character’ – if the protagonist is a scientist. (Dudman 2014)

Kingsolver’s Ovid Byron, lepidopterist and ecologist, is portrayed as dedicated to his research task of measuring the dislocated monarch butterflies’ response to an alien climate but clinically detached. He rejects any plan to rescue them from likely extinction in freezing temperatures: ““That is a concern of conscience.

Not of biology” (Kingsolver 2012, 319). Like Gaines’s Tina, Byron subscribes to the professional scientist’s refusal to claim more for the thesis of climate change than is strictly proven, but comments bitterly, “As long as we won’t commit to knowing everything, the presumption is we know nothing” (Kingsolver 2012, 350). He is also fearful of peer criticism: “If we tangle too much in the public debate, our peers will criticise our language as imprecise, or too certain. Too theatrical. [...] Having a popular audience can get us pegged as second-rank scholars” (Kingsolver 2012, 323).

The Echo Maker explores the plasticity of identity, substituting it for “the old stable ego of character” (Lawrence 1970, 87). In this sense, it is closer to the Jamesian ideal, where we can only infer what characters are like from a combination of what they themselves believe and the way others respond to them, factors that can be antithetical. Each one is opaque to the others. Powers claims:

To this end, my technique was what some scholars of narrative have called double voicing. Every section of the book (until a few passages at the end) is so closely focalised through Mark, Karin, or Weber that even the narration of material events is voiced entirely through their cognitive process: the world is nothing more than what these sensibilities assemble, without any appeal to outside authority. (Champion 2006, n. pag.)

5 Getting the Science ‘Right’

Mary Shelley famously described Frankenstein’s fascination with the medieval alchemists and his obsession with overcoming the bounds of life and death, but she writes almost nothing about the actual procedures her “student of pale arts” embarked upon. Yet, such is the power of the novel that we clearly envisage Frankenstein labouring in his secret laboratory. “In a solitary chamber, or rather cell, at the top of the house, and separated from all the other apartments by a gallery and a staircase, I kept my workshop of filthy creation” (Shelley 1996, 32).

Such sleight-of-hand descriptions would be unacceptable in science novels today. The expectation of accuracy, or at least of plausibility, runs high, especially with readers who are also scientists. Novelist Bernhard Kegel, trained in chemistry and biology, asserts, “When I read a book where there are many mistakes in the science, I can’t read it” (Kegel 2014).

Many contemporary writers are familiar with some branch of science, usually the discipline featured in the novel – Goldstein in mathematics and physics, Mawer in genetics, Gaines in chemistry and oceanography, Dudman in organic chemistry, Goldschmidt in astronomy, Kingsolver in biology. Powers read physics and worked for a time as a computer-programmer (Berger 2002–2003, n. pag.).

Those who lack such exposure to science may shadow a scientist (as Ian McEwan assiduously did for two years in preparation for writing *Saturday*),² and even those with a science background may read extensively in the subject or visit a key milieu to note the ambience of place, as Mawer did at Brno and Dudman in Greenland. Dudman read Wegener's papers and his diaries to capture his 'voice' and thought processes, discovering there a lyricism, an intensity and an overriding curiosity that she built into the fictional character. Having retraced his life journey she says:

At each place I tried to imagine being Wegener. I made notes on how the place felt, what I saw and heard [...] and incorporated these details in the book to try and make it more convincing.

One thing which impressed me so much that I used it as the ending of the novel, was seeing a sun pillar in Greenland. I knew Wegener was interested in these optical effects, and was one of the first people to explain them, so it fitted in very well. (Dudman 2014)

Already trained in genetics, Mawer also studied all Mendel's writings in detail. Visiting the convent where Mendel was a friar and later abbot he found that, in Mendel's time, it was not isolated, as in the accepted legend, but close to Vienna and itself a centre of intellectual activity (Mawer 2014). In creating his modern geneticist, Dr. Benedict (Ben) Lambert, he specifically studied the genetics of achondroplasia (a form of inherited dwarfism) and drew on his knowledge of a person with this condition (Mawer 2014), so Ben, who carries this genetic factor, is described with great accuracy as well as imagination. The many accounts of genetics in the text and the footnote references are scrupulously correct; the twenty-one chapter headings all refer to important terms in genetics, and genetic jokes are scattered throughout for the pleasure of genetically literate readers.

For Goldstein, little research was necessary. She had been a close observer of the group of mathematicians and theoretical physicists who collected around her first husband Shelley Goldstein to discuss quantum mechanics and relativity. Among the group was David Bohm, whose obsession with 'hidden variables' (which Shelley Goldstein later named Bohmian mechanics) was the inspiration for Mallach in *Properties of Light*, as Goldstein explicitly announced in the "Afterword":

Samuel Mallach is a Bohm-inspired character, with virtually all the fundamental facts of Bohm's life changed. [...] What has been lifted straight from the life is his deterministic model for quantum mechanics and the dismissive treatment it received from the established physics community. (Goldstein 2001, 243)

² McEwan work-shadowed neurosurgeon Neil Kitchen at the National Hospital for Neurology and Neurosurgery, London (McEwan 2005, 282).

In *The Echo Maker*, Powers' cognitive neurologist Gerald Weber, famous for his best-selling anecdotal case histories of patients with unusual mental states, instinctively diagnoses all those he encounters. Throughout the novel Powers creates a level of authenticity for Weber by studding his discourse with specialist psychiatric terminology, though this impinges adversely on the flow of the novel: "Korsakoff's Confabulation, malnutrition from alcohol abuse," akinopsia, hemispacial neglect, asomatognosia, (Powers 2006, 105; 124; 160; 163–164). A confirmed mechanist, Weber substitutes a chain of biochemical reactions for intuitive notions of memory and self.

Some thought sent an action potential down an axon. A little glutamate jumped the gap, found a receptor on the target dendrite, and triggered an action potential in the second cell. But then came the *real* fire: the action potential in the receiver cell kicked out a magnesium block from another kind of receptor, calcium flowed in, and all chemical hell broke loose. Genes activated, producing new proteins, which flowed back to the synapse and remodelled it. And that made a new memory, the canyon down which thought flowed. Spirit from matter. (Powers 2006, 381, emphasis in the original)

However, Weber's armoury of scientific terms and biological mechanisms is insufficient to prevent his trajectory from authoritative self-sufficiency to disempowerment and self-doubt as both his colleagues and the public tire of his outmoded anecdotal case studies, now superseded by clinical tools – brain scans and biochemical tests. Weber is savaged by the audience after a lecture and a critic describes his latest book as "familiar and slightly cartoonish tales [...] [while] his stories border on privacy violations and sideshow exploitation [...] unacknowledged research and unfelt suffering" (Powers 2006, 221).

In negotiating the relation between reality and fiction, authenticity and plausibility may be more important than strict accuracy, which may be too complex and distracting for the reader. Albert Camus remarked, "Fiction is the lie through which we tell the truth" (Camus n.d.) and in *The Mind-Body Problem*, Goldstein, needing to invent a new kind of number for twelve-year-old math prodigy Noam Himmel to discover, devised the name 'supernaturals' for these fictitious numbers beyond the natural numbers. So plausible were these non-existent numbers that they were accepted as real, even by several mathematicians, who claimed to have found a proof for their existence (Goldstein 2014).

Similarly, Mawer needed Ben Lambert to produce a seminal article on the location of the gene for achondroplasia, so he 'gave' him two papers recently published at the time of writing the novel, the only ones not footnoted in the text because they were fictitiously attributed to Ben.

In *Carbon Dreams*, Tina's research projects are fictional but entirely plausible because they are based on sound scientific principles. "They are, in essence,

armchair experiments, developed in a credible manner, with results that fit plausibly into gaps in our knowledge” (Gaines 2001, 353). Gaines comments: “In fact actual research went in that direction, but I didn’t know that when I wrote the novel” (Gaines 2014). The instrument that Tina is described as using in the novel “is not actually what you would use for this type of work, but it was a much more convenient type of instrument that I could be poetic about” (Gaines 2014).

6 Integrating the Science – Avoiding the ‘Information Dump’

The introduction of technical information, scientific concepts and social outcomes is a major hazard for the novelist but the writers discussed in this paper have employed a broad palette of techniques to avoid destroying the illusion of the narrative. The most direct and concise means of disseminating information is the lecture, but artistically this is the most dangerous and is rarely used. Mawer, however, dares and succeeds. The novel opens with Dr. Benedict Lambert delivering an address to members of the Mendel Symposium. Subsequently, and immediately following the account of a public lecture allegedly given by Gregor Mendel on the results of his hybridising experiments with peas, Ben expounds at great length the condition of achondroplasia, during which he gives the DNA sequence of the gene responsible for this (Mawer 1999a, 195–201), and later embarks on a lecture about eugenics past, present and future (Mawer 1999a, 268–273). This daring technique, which violates the conventions of novel composition, succeeds in the case of Mendel because it is indicative of his obsessive nature: “He must have been obsessive to carry out the work he did without assistance, without encouragement, without support” (Mawer 1999b, 8). It also succeeds in the case of Ben, whose witty and dramatic lecturing style is a credible expression of his personal need to proclaim his expertise and authority in genetics, and to preempt and discomfort his audience (including the reader), daring them to pity the disability that genetics has laid upon him:

It was [...] the kind of place where monsters were put on display, the kind of place where people with deformities were exhibited for all the world to gaze at in horror and revulsion and amusement. People like me [...]. And you, ladies and gentlemen, would have gone to stare. At people like me. (Mawer 1999a, 2–3)

A more discreet form of the lecture is the explanation delivered to a non-initiate who stands in for the reader. This common technique is most successful when

it appears to evolve naturally from the characters' personalities and situation. Thus, Friar Mendel explains in detail the results of his experiments with peas to Frau Rotwang but into this otherwise dry information exchange is interpolated a little drama involving the reactions of a celibate priest, sexually attracted to a pretty married woman, whose feigned interest in his discourse is a socially acceptable expression of the sexual undercurrent of her feelings for him (Mawer 1999a, 96–98).

Similarly, Ben's efforts to explain elementary genetics to Jean Piercy are punctuated by her prudish interjections and Ben's double-entendres, introducing a level of humour, which effortlessly integrates the information within the narrative. When Ben tells her that DNA molecules are in all her cells, Jean is shocked: "'You mean' – a frown puckers her forehead – 'it's there at this moment, wriggling around inside me?' She shifts on her seat. As though things are moving beneath her skirt" (Mawer 1999a, 112). In footnotes scattered throughout, Ben compulsively associates human phenotypes with their genetic basis: cleft chins and curly hair (autosomal dominant), blue eyes (autosomal recessive, probably controlled by genes at two different loci), black skin (polygenic control), baldness (sex-limited autosomal dominant) (Mawer 1999a, 1). While conveying valid information these parentheses also function as expressions of Ben's pedantic knowledge and playful pomposity and, through Mawer's use of humour, are more successfully integrated than Weber's tedious terminology in *The Echo Maker*.

In *The Falling Sky*, Goldschmidt also has recourse to a variety of scientific explanations. Her protagonist Jeannette discusses with her colleague Maggie the significance of their observational results and conducts a seminar for first-year astronomy students, in whom she labours to instil the fundamentals of the Big Bang theory, a focal point of the novel. Lured into participating in a TV programme with an aggressive amateur astronomer hopeful of exploiting her apparent discovery to overthrow the established theory, she is forced to discuss on air the reasons for her reticence to do so (Goldschmidt 2013).

In *Flight Behavior*, Byron explains to Dellarobia the annual flight of the monarch butterflies and the probable reasons for their abnormal winter migration to eastern Tennessee.³ Dellarobia, an uneducated but quick-witted woman who is naturally curious about the world, becomes his assistant; thus information can be delivered in small packets in response to specific incidents and questions, interleaved with Dellarobia's immediate survival concerns and her growing attraction to Byron. The larger-scale issue of climate change and why it is resisted

³ Some 150 million monarch butterflies migrate annually from the north-eastern US and Canada to winter in the warmer fir forests of the Michoacan mountains in Mexico.

by so many is debated vigorously between characters of diverse background: Byron the scientist, Dellarobia, her inept farmer-husband Cub and his parents, the media person who interviews Byron, and the impassioned environmentalist who hands out questionnaires urging passers-by to shrink their carbon footprint are all representative participants in the discussion. This diversity of views precludes simple didacticism and propaganda.

Of *Carbon Dreams* Gaines has said:

I wanted to say right up front ‘this book is about science.’ I wanted the science to be centre stage. I knew that if I wanted readers to be engaged with the process of research there had to be enough science to explain the concepts, not just background.

My challenge was to engage readers at all levels. So one of my strategies was to explain the research to characters with different levels of understanding: Tina’s own thoughts, the seminar of experts in the field; Katharine, another scientist but in a different discipline; and, very importantly, Chip, a non-scientist, who is nevertheless persistent in trying to understand. (Gaines 2014)

But Chip, an autodidactic farmer who becomes Tina’s lover, is more than merely a passive listener. He engages her in debate about her social responsibility for publicising her results in the popular press as counter-arguments to the propaganda of the oil companies that deny the possibility of climate change. Here, as in *Flight Behavior*, the stimulus to communicate the science comes not from a scientist but from a socially aware lay-person.

Dudman’s Wegener frequently soliloquises about his ideas as he slowly accumulates the evidence for his theory of Continental Drift. Once he delivers a monologue to his sleeping baby daughter Hilde, in which he reviews his proofs in simple language, as though she could understand (Dudman 2003, 236–237). He also presents lectures to learned societies and discusses his ideas with his father-in-law and former mentor, the meteorologist and climatologist Wladimir Köppen (Dudman 2003, 252–255).

In *The Echo Maker*, the focus of the novel is Mark Schulter, who, after a road accident, develops Capgras’s syndrome,⁴ “a kind of amnesia of affection” (Whitehead 2006, n. pag.), which Powers describes in great detail through the interchanges of Weber with the local psychiatrist Hayes and in his explanations to Mark’s sister Karin, whose knowledge of neuroscience is minimal.

To those not trained in it, mathematics is widely regarded as the most opaque of the sciences, so portraying characters thinking about higher maths presents a

⁴ Capgras’s syndrome is a form of delusional misidentification, whereby the person affected recognises formerly close family members, but because they trigger no emotional response, believes they are impostors or aliens and angrily rejects them. Mark Schulter rejects his sister Karin and his dog but not the friends with whom he has a more distant connection.

considerable difficulty. One solution is to have non-mathematicians as narrators. Thus, whereas in the above examples the characters articulate a professional understanding of their own research area, Boyd in *Brazzaville Beach* employs a different mode of communication. John Clearwater's mathematical explorations are conveyed through his wife Hope, a biologist who does not understand them and tries in vain to relate them to her chaotic life. This suggests both the relevance of such concepts as turbulence and divergence syndromes to the discontinuous phenomena of lived experience, and the experiential irrelevance of the mathematical theories and formulae that attempt to define them. Similarly, in *The Mind-Body Problem* Goldstein denies Noam Himmel, another mathematician, a voice. His alleged "genius" is relayed only through his wife Renee, whose original admiration is subverted by her incomprehension and growing hatred.

7 Structure and Imagery

A more complex, but ultimately more integrated technique for including scientific content is the expression of meaning through structure and imagery, through confining the reader within the mental world of the novel's internal focaliser and/or translating scientific concepts into the language of common experience.

In *Brazzaville Beach*, *The Falling Sky* and *Properties of Light*, the chronotopic structure mimics Einstein's perception of space-time as fluid. Boyd's novel flicks back and forth in time and in place, uniting temporally separated incidents in Hope Clearwater's life in a seemingly random manner, enacting the mathematical concepts of convergence and turbulence that so preoccupy her husband. Goldschmidt adheres to a more regular pattern using alternating "Then" and "Now" chapters, of which the latter occur in a temporal progression while the former emerge from random points in past time. In effect, this demonstrates the interaction of Jeannette's experiences as a scientist with those of her private life and accounts for her psychological need for the Big Bang as a stable, unifying theory that gives structure to her inner and outer worlds.

Goldstein uses repetition and the revisiting of incidents to simulate the uncertainty of quantum physics and the impossibility of resolving Schrödinger's famous thought experiment based on a paradox. Goldstein further recreates the fundamental postulates of quantum mechanics, the intellectual problem which Mallach, Dana and Justin are all obsessively focused on resolving, by imprisoning the reader, like the characters themselves, in a state of ontological uncertainty about what is 'real' or 'not real.' Justin first sees Dana in a mirror and thinks she is a portrait, i.e. 'not real.' The question of Justin's physical reality is

also problematic. It is some time before we realise that this narrator is a ghost. Similarly, the ongoing influences of the past, even the dead (Justin's parents, Mallach's wife, and the narrator Justin Childs himself) are piquant examples of the concepts of non-locality and entanglement in which all the characters are entwined.⁵

Here we should note that Goldstein's title is far from innocent. The term 'Properties' references the notion that 'properties' in the scientific sense are not merely descriptions of particular things but may in fact be those particulars, the primary entities. That is, what we call a 'thing' is essentially a bundle of properties (Kuhlmann 2013, 45). Similarly, light is an immensely controversial physical concept, sometimes behaving like particles (photons) at other times like waves, but always distinguished and definable by its properties and effects. There is a recurrent image of moths attracted to the light, symbolic of Mallach, Justin and Dana compulsively fixated on their mathematical problem, only to perish or emerge permanently wounded.

In *Properties of Light*, cascades of imagery bridge the concepts of physics and poetry through the numerous references to Blake and Yeats and through an insistence that scientific knowledge is essentially intuitive rather than rational. The eureka moments for Mallach and Dana come when they dance the solution to their physics problem:

He [Mallach] felt the physics within himself, within the muscles of his own body. He told Justin this. He showed him. He danced for him once the movements of light in the two-slit experiment, the experiment that seems to lead paradoxically to the conclusion that light is like both wave and particle. [...] Mallach had danced away the paradox. (Goldstein 2001, 46)

Dana, too, as a young girl, "had danced out the progression of the gyroscope" (Goldstein 2001, 200) and later leads her students in dancing the math, imaging the abstract pattern in bodily experience.

In contrast to the temporal acrobatics of the preceding novels, *Mendel's Dwarf*, *Carbon Dreams*, *Wegener's Jigsaw*, *The Echo Maker* and *Flight Behavior* follow a chronologically simple narrative structure, symbolising the slow piecing together of a theory that will ultimately make sense of the data. Symbols and images translate scientific concepts into common experience.

In *Mendel's Dwarf*, the frequent insertion of sections about Mendel and his seminal work in genetics within the narrative of twentieth-century geneticist,

⁵ In quantum physics, an entangled system is one in which individual components cannot be described or understood without considering the others (Peres 1993, 115).

Ben Lambert, leads us to compare and contrast their approaches. Mawer remarks, “I got the idea of looking at investigative science, the idea of scientific discovery, in each of the two centuries and how they differed” (Mawer 2014). Mawer is also inventive in illustrating scientific concepts in terms that the reader can relate to. He explains the nature and size of genes through Ben’s dream of a railway line, where the rails are metaphors for the double-strand DNA molecule with transcriptional starting points as ‘signal/promoter boxes,’ identified by the sequence of thymine and adenine nucleobases – TATA.

[T]he empty tracks stretch away into the distance while the train sweeps along. [...] the track is everything, the sum total of perception. [...] Sometimes, rarely, there is a disturbance: a signal flashes past, followed by a signal box with a name written on it [...] TATA [...] and after it comes the sudden relief of a station [...] a long and bewildering nameboard like an anagram in a crossword, and then there is the open line again, [...] the flashing sleepers, thousands and thousands of them, all without meaning or sense or significance. (Mawer 1999a, 110)

Mawer explains:

And then the train goes on and that was the gene. You’ve got miles and miles and miles and miles of just empty track between genes and at the time when I wrote we hadn’t even discovered that we’ve only got 23,000 genes. (Mawer 2014)

Dudman similarly evokes concrete images to explain the movement of continents to the lay reader: the recurrent sense Wegener has of the earth in constant motion (Dudman 2003, 16; 182; 236; 296) and his demonstration of rocks bending like wax (Dudman 2003, 296).

In *The Echo Maker*, Powers, through Weber, endeavours to convince us that we are all victims of Capgras’s syndrome or something similar: we are all located on a spectrum of mental disorders. This is reinforced by the multifunctional image from which this novel takes its title, the sandhill cranes, whose Cherokee name means ‘echo maker’ (Ness 2007, n. pag.). Each section begins with reference to “one of the greatest wildlife spectacles on the planet” (Appleyard 2007, n. pag.), hundreds of thousands of such cranes settling on the Platte River in Nebraska during their annual migration. As well as providing continuity the cranes become elements in the environmental war over riparian developments encroaching on the birds’ landing areas and removal of water from the Platte to accommodate the needs of tourists who, ironically, have come to see the spectacle of the massed birds. We learn that the cranes’ sense of location during migration depends on their connection and recognition of each other, an ability that victims of Capgras’s syndrome clearly lack. Powers implicitly raises the

possibility that we are all such victims since we do not recognise our relationship to the cranes – or to each other.

8 Paratextual Content

Gérard Genette has called the paratext “a privileged place of pragmatics and a strategy, of an influence on the public, an influence that [...] is at the service of a better reception for the text and a more pertinent reading of it” (Genette 1997, 1). In the early novel, paratextual content was often used to bridge the gap between the real and the fictional. In the science novel, where fictionality is an accepted convention, paratexts have a different function. They deliver additional scientific information and provide reassurance of authenticity without intruding on the narrative structure.

Common paratextual forms in the science novel are an author’s preface or afterword, often relating to scientific data used in the novel, appended study guides, reviews, references, illustrations or authors’ websites. While standing outside the main narrative these devices amplify the science content and affect how we read, interpret, trust and understand the central text.

Within our selection of novels, Dudman adds an “Author’s Note” on the modern explanation of Plate Tectonics and how this evolved from Wegener’s Continental Drift theory. She scrupulously lists the few points at which the novel diverges from real events, as well as providing an extract from the *New York Times* just after Wegener’s death and an extensive reading list. *Carbon Dreams* also carries an “Author’s Note and Selected References” linking the geochemical processes in the novel to those actually in use at the time and citing references to the ideas Tina develops and contemporary texts about global warming and greenhouse gas emissions. It also refers to scientific papers and books that discuss the scientific themes of the novel, including global warming. The “Afterword” to *Properties of Light* provides a mini-biography of David Bohm and explains the similarities and differences between the real Bohm and the “Bohm-inspired character” Samuel Mallach. Kingsolver also adds an “Afterword” expanding on the devastating mudslides and flooding of the Mexican town of Anganguero, the area where the monarch butterflies overwinter, as referred to in the novel, while acknowledging that their relocation to the Appalachians is fictional. She also reaffirms the message of climate change by acknowledging the research records and insights of experts in the field.

The Penguin edition of *Mendel’s Dwarf* carries both an Introduction and a “Conversation with Simon Mawer,” in which the author amplifies some of the

political issues in the novel and in passing demonstrates his own authority in genetics. This “Conversation” is followed by “Questions for Discussion” which draw attention to specific, factual issues in the text. Interviews with many of the authors have been published, providing more information about the background of their novels.⁶ Most science novelists provide extra information about their novels on their official websites – interviews, videoclips of lectures, answers to readers’ questions. Simon Mawer’s website includes a photo essay on Mendel and promotes a non-fiction book, *Gregor Mendel: Planting the Seeds of Genetics* as background information for the novel.

For the curious reader, these additions supplement information conveyed within the novel without impinging on its artistic unity or providing more detail than the casual reader may want.

9 Phenomenology: Conveying the Scientific Experience

We have seen that Goldschmidt’s primary intention was to convey to readers the experience of being an observer at a large telescope on a remote observatory site. “I wanted to write a novel exploring the process of doing astronomy, what it actually felt like from the inside” (Goldschmidt 2014). A unique feature of the science novel, compared with other forms of the genre, is its ability to convey the consciousness of scientists in a research laboratory, engaged in field work, observing at a telescope, obsessed with solving a problem in maths or physics or pursuing a theory. This is particularly true in an autodiegetic novel such as *Wegener’s Jigsaw*, where the narrative is focalised exclusively through Wegener’s consciousness, conveying what the events he describes seemed like to him at the time, his thoughts and feelings, his aesthetic awareness. In *Properties of Light*, the autodiegetic narrator is Justin, a mathematician, who understands and shares the passionate obsession with which the two other major characters pursue a mathematical explanation of the physics.

But even in other homodiegetic novels, the writers project, often from their own experience, the excitement of pursuing an idea, the physical

⁶ Other science novelists have employed additional paratexts. Bernhard Kegel adds background information for his novels on his website and Margaret Atwood (or her public relations team) engages in on-going conversation with readers about her novels in blogs and tweets. The author’s acknowledgements may also provide evidence of authenticity. Ian McEwan’s *Saturday* acknowledges the neurosurgeon Neil Kitchen and other specialists for their input, thereby affirming the accuracy of the scientific content.

and mental risks that may attend that pursuit, the long periods of frustration, boredom and inactivity; the not infrequent sense of failure when one's research or theory is rejected or, worse, ignored, and the subsequent depression or madness.

10 Conclusion: Making Science Matter

The authors' comments quoted here indicate that the original impetus to write a science novel was often a desire to bring forward a topic for public discussion. *Carbon Dreams*, *Flight Behavior* and *The Echo Maker* deal with aspects of climate change, *Properties of Light* with the nature of reality, *Mendel's Dwarf* with eugenics and genetic engineering. The challenge for the novelist is to include discussion of broad-scale topics that affect humanity and the planet, along with the scientific data that provide the evidence, while still retaining the human interest of individuals caught up in these issues.

Mawer is the most audaciously didactic, not only in the detailed information he includes about genetics, but in Ben's lecture about the politicisation of genetics: eugenic sterilisation as practised in the Third Reich, Lysenkoism in the USSR and, not least, although least publicly acknowledged, contemporary, 'acceptable' 'eugenics of the market place' in the form of embryo selection, euphemised as 'family balancing' or screening for genetic diseases (Mawer 1999a, 271; 273). He sets out the scientific facts while implying the deeply problematic social consequences. Ironically, even as Ben is giving this moralising lecture, the child he has created by his own embryo selection is being born.

In other novels, it is a non-scientist character who points out the wider importance of the science. In *Carbon Dreams*, it is Chip who persuades Tina of the importance of her research in countering the vested interests of climate-change deniers. In *Flight Behaviour*, Ovid Byron rebukes Dellarobia for her eagerness to save the perishing butterflies, declaring "Science doesn't tell us what we should do. It only tells us what is," to which Dellarobia replies tartly, "That must be why people don't like it" (Kingsolver 2012, 320). Byron holds the view that scientists should be emotionally disinterested: "We are scientists. Our job is only to describe what exists" (Kingsolver 2012, 147). However, the novelist's job is both: to present the science dispassionately and to explore the consequences and human responses that makes it matter. In Henry James's words, "It is art that *makes* life, makes interest, makes importance, for our consideration and application of these things" (James 1958, 267, emphasis in the original).

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