The perils of popularising science

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Science has lost much of its attraction over recent years. The number of upper school and university students taking the sciences, and its Siamese twin mathematics, appears to be declining. It is difficult to pin-point why. The poor salaries paid to scientists—compared, say, to arbitrageurs and bank executives—might be one factor. Another might be fashion: science is just not seen as cool by many youngsters. Another might be the influence of radio shock-jocks and other scientifically illiterate commentators given air- and page-space to ridicule those views of scientists at odds with their own. (A pertinent example here is rancorous hectoring by client-change deniers.) Another factor might be a creeping suspicion that scientists are insufficiently concerned about the potential side-effects of their discoveries. The atomic bomb, genetically modified food and stem cells extracted from human embryos are just some of the activities that some see as having a morally dark side. Science, then, might not necessarily be for the good of all, a view possibly reinforced by that fact that so much scientific research these days is funded by organisations whose primary goal is not discovery but private profit.

The astute politician will sense this new anti-science zeitgeist and, with their ready access to the media, may give voice to it (especially if there are votes on offer). This can only amplify science scepticism, making what may have been only a ripple in the current of popular opinion into a tide of opposition. For instance, Rick Santorum, a candidate for the Republican Party nomination to challenge Barack Obama in the 2012 US presidential election, has been fuelling what was once only a fringe view, namely, that science is the mouthpiece of political ideologies:

> "One of the favorite things of the left is to use your sentimentality, and your proper understanding and belief that we are stewards of this earth and we have a responsibility to hand off a beautiful earth to the next generation. They use that and they have used it in the past to try to scare you into supporting radical ideas on the environment. They tried it with this idea, this politicization of science called man-made global warming … I stood up and fought against those things. Why? Because they will destroy the very foundation of prosperity in our country."[1]

1. Quoted from http://www.huffingtonpost.com/richard-schiffman/rick-santorum-statements_b_1293657.html.

What will science sceptics do if they get into government? What is happening in Canada may give us a clue:

> "The Harper government has abandoned Canada's climate commitments, cut back on science spending and muzzled government scientists who stray from the official line."[2]

It is clear that science has lost, and is losing, respect. But whatever the cause or rate of the decline in the study of science, it is clear that without more research in the sciences, the earth and the multifarious lives it harbours is at serious risk. The looming prospect of a hostile climate, diminishing resources and vaccine-resistant viruses—to mention just a few of many—is unlikely to be thwarted by arbitrageurs and bank executives. It will thwarted, if thwarted at all, by scientists, in their customarily rigorous application of the Baconian scientific method.

The decline in interest in science just as science is more than ever needed has not gone unnoticed, and moves have been afoot to reverse the decline. Some universities have created posts to popularise science. For example, in 1995 Oxford University created the *Simonyi Professorship for the Public Understanding of Science* (a post first held by Richard Dawkins and now held by Marcus du Sautoy). Further, the last few decades has seen a boom in the publication of popular science books and magazines. Even high street bookshops these days sport shelves labelled *Popular Science*. The hope seems to be that by popularising science, and mathematics, more and more youngsters will be develop a passion to take up study in these fields

But science is a difficult subject, whatever sub-discipline you consider. Its concepts are mostly abstract (what is a magnetic field?), its discoveries often counter-intuitive (how can widely separated photons be entangled?) and the mathematics needed to describe its discoveries is sometimes barely understood even by university-trained mathematicians (the Navier–Stokes equations, for example). This all makes popularising science a difficult act, somewhat akin to walking a tightrope. Make it too simple and it will inspire few; make it too difficult and eyes will glaze over.

Popularisers, then, need to walk a path between yawning simplicity and daunting complexity. It is a difficult act, and the temptation to over-simplify is no doubt strong. And there lies a risk that threatens the very purpose of trying to make science more popular. A book that attempts to popularise science must assume that readers will have some prior knowledge of science and mathematics. For example, Stephen Hawking's book *The grand design* might have a glossary at the back describing what an atom is, but the book is unlikely to be bought, and even less likely to be understood, by someone who does not have a reasonable understanding of physics and cosmology. A bookkeeper, say, with no prior studies in upper school or university science will simply find the material beyond them. Likewise with Marcus du Sautoy's *The number mysteries*. On opening this book, a bookshop browser will encounter mathematical equations, some quite complex indeed. If that browser has no prior studies in upper school or university mathematics, they are more likely to return the book to the shelf than buy it.

So we must assume that readers of popular science books and magazines bring to their reading some not insubstantial understanding of science and mathematics. Moreover, we must assume that not everyone who reads such books inclines favourably towards science. For is it not possible that, say, climate-change deniers, and others hostile to science, might also read such books?

So popularisers of science and mathematics need to be careful not to over-simplify—lest they score an own goal. The interested non-specialist may well have enough background in the subject to spot the simplification. If they think kindly of the sciences, the harm might be little more than a private devaluing of the book. On the hand, if they are science agnostics, or even

2. B. Holmes, "Oh, Canada!", *New Scientists*, 31 March 2012, p. 26.

science deniers, a spotted over-simplification might only further fuel their distrust of science and scientists. They might subsequently discourage others from studying science, thwarting the very purpose of popularising. Or they might ridicule the science in the press or the web. Or worse still, they might smudge the air-waves with virulent commentary that sways poorly-schooled listeners to think harshly of science.

In this paper I'm going to look at a number of instances of over-simplification. The purpose is not to ridicule the authors. Rather, the purpose is simply to highlight how easy it is for authors—even those whose reputations are unimpeacable—to slip up in their simplifications, thereby potentially giving fuel to the enemies of science. Perhaps this paper will cause future popularisers to pause and reflect on the possibly unwanted side-effects of each simplification they make and, if necessary, recast it in a way that gives no support to those who think that science is a dark, misguided, conspiratorial endeavour.

Before we start, let's note that simplification comes in many hues. A fairly harmless variety is the making of an unqualified statement when its truth is known to be conditional. *Water boils at 100 °C* is an example. Simplification of this sort is fairly harmless. Indeed, if everything we said had to be strictly correct, with every qualification in place, scientific communication would become glacial. Other relatively harmless forms of simplification include artist's impressions, similes, metaphors and the modelling of complex systems. But some forms of simplification do raise concerns. Two such forms involve shortcuts in logic and definitional sleights-of-hand. These two are discussed below by way of some recent examples.

I will consider two recent publications, each aimed at the interested non-expert: Stephen Hawking's *The grand design* (2010) and Marcus du Sautoy's *The number mysteries* (2011). Hawking's book exhibits some logical howlers, and du Sautoy's book plays loose with definitions to prove points (some of which appear to be provided purely for their likely sensational appeal). None of the flaws I discuss overthrows anything of scientific or mathematical significance. No explanatory scaffolding is dismantled, no hypotheses over-turned. But the flaws will—naturally if unfairly—spread tentacles of doubt throughout the books and may bolster the scorn of those readers who incline towards science-denial.

Stephen Hawking is, by any conceivable measure, a genius. The former Lucasian Professor of Mathematics at the University of Cambridge is the unmistakable giant in theoretical cosmology, despite suffering from motor neurone disease for most of the last fifty years. He has written a number of book popularising science, including some for children. But on occasion, his attempts to popularise have led to simplifications that fall foul of some fundamental rules of logic. Consider the following extract from his latest book, *The grand design* (co-authored with Leonard Mlodinow):

> "Maxwell … showed that electromagnetic fields could propagate through space as a wave. The speed of that wave is governed by a number that appeared in his equations, which he calculated from experimental data that had been measured a few years earlier. To his astonishment, the speed he calculated equalled the speed of light, which was then known experimentally to an accuracy of 1 percent. *He had discovered that light itself is an electromagnetic wave*." (p. 91)

The skeleton of Hawking's argument clearly shows that it is fallacious:

Premise 1: If a thing is an electromagnetic wave, it travels through space at speed *c*.
Premise 2: This particular thing—light—travels through space at speed *c*.

Conclusion: Therefore this particular thing—light—is an electromagnetic wave.

But the fact that two things share one attribute in no way implies that they must share any other attribute. If at the same instant I drop a vase and a hammer from the top of a tall building, at each moment of their descent their speeds will be identical (since, as Galileo showed, all objects fall to earth at the same rate of acceleration). Does that mean that we can infer that a vase and a hammer are the same thing?

A simple parallel should make the error in Hawking's syllogism clear:

> If it is raining, the ground is wet [premise 1: If *antecedent*, then *consequent*]
> The ground is wet [premise 2: affirming the *consequent*]
> Therefore it is raining [conclusion: *antecedent*]

This is an example of what is known as the *fallacy of affirming the consequent*. The argument is fallacious because there are, obviously, many possible causes for the ground being wet, not just rain. I could have just washed the car; there might have been a heavy dew; a water main may have burst; and so on. In other words, the premises could be true and the conclusion false— the usual definition of a fallacy.

The companion fallacy is the *fallacy of denying the antecedent*. Here is an example:

> If it is raining, the ground is wet [premise 1: If *antecedent*, then *consequent*]
> It is not raining [premise 2: denying the *antecedent*]
> Therefore the ground is not wet [conclusion: denying the *consequent*]

Hawking, in same book, appears to fall foul of this fallacy too:

> "Recent experiments in neuroscience support the view that it is our physical brain, following the known laws of science, that determines our actions, and not some agency that exists outside those laws. For example, a study of patients undergoing awake brain surgery found that by electrically stimulating the appropriate regions of the brain, one could create in the patient the desire to move the hand, arm or foot, or to move the lips and talk. It is hard to imagine how free will can operate if our behaviour is determined by physical law, so it seems that we are no more than biological machines and that free will is just an illusion." (p. 32)

Stripped to its bare bones, Hawking's argument is this:

> Premise 1: If we stimulate appropriate regions of the brain, a person's hands, feet, arms and lips move
> Premise 2: This person's brain is not being stimulated
> ___
> Conclusion: Therefore this person's hands, feet, arms and lips are not moving

The fallacy is in the assumption that *only* by electrical stimulation of the brain—by artificial or natural means—will a person's hands, feet, arms and lips move. The proof is incomplete. It needs also to be established that the hands, feet, arms and lips *cannot* move by any other means. Even then it needs to be established that the hands, feet, arms and lips are not moved by the effect of other structures in the brain acting, on free decision, on the parts stimulated by the neuroscientists. A parallel: when I light the gas under a kettle [when parts of my frontal lobe are stimulated] the water in the kettle boils [I begin to talk]. But does the lit gas [stimulated lobe] ultimately cause the kettle to boil [me to speak]? Wasn't there a prior intention on my part to light the gas [to talk]? To rule out possibility of a prior, intentional cause, more information is needed. But Hawking does not provide it, and thus leaves readers pondering just how strong the argument against free will really is. A weak argument such as this diminishes the potency of other arguments in the work. It might be an unfair inference, but it is a natural one: a sloppy argument here means probable sloppiness elsewhere.

Of course, the fallaciousness of *one* argument in favour of a particular position doesn't mean that that position is false. It just means that the arguer needs stronger arguments. Hawking might well be right in believing that we have no free will—indeed a constellation of separate investigations is making that view increasingly likely—but the argument put forward in Hawking's book is not a knock-down argument. It is simply invalid: logically invalid. The premises and conclusion might well be true while the conclusion is false.

In 2008 mathematician Marcus du Sautoy took over the *Simonyi Professorship for the Public Understanding of Science* at Oxford University from Richard Dawkins. The *Simonyi Professorship* website states that:

> "The aim of the Simonyi Professorship is to contribute to the understanding of science by the public … The task of communicating science to the layman is not a simple one. In particular it is imperative for the post holder to avoid oversimplifying ideas, and presenting exaggerated claims."[3]

Du Sautoy has a well-deserved reputation as a brilliant mathematician and he has written four books that many will think are attempting the impossible: to popularise mathematics. His latest book—*The number mysteries*—was written after he took up the Simonyi Professorship. It is well within the popular genre, but there are passages where the reader could be forgiven for thinking that du Sautoy, contrary to the Simonyi aims, is oversimplifying and exaggerating. This suspicion comes to the forefront in a number of passages where he plays loose with language. I'll consider two such passages.

In a section titled *How can a shape be 1.26 dimensional*, du Sautoy writes:

> "Imagine taking a sheet of transparent graph paper, laying it over a shape and counting how many squares contain part of the shape. Next, take a sheet of graph paper whose squares are half the size of those on the first piece.
>
> "If the shape is a line, the number of square son the graph paper goes up simply by a factor of two. If the shape is a solid square, the number of squares goes up by a factor of 4 or 2^2. Each time we halve the size of the grid on the grid paper, the number of squares meeting a one-dimensional shape increases by $2 = 2^1$, while for a two-dimensional shape the number increases by 2^2. The dimension corresponds to the power of 2.
>
> "The curious thing is that if you apply this procedure to the fractal [just discussed], when we halve the grid size of the graph paper, the number of squares that contain part of the [fractal] goes up by a factor of approximately $2^{1.26}$. So from this perspective the dimension of the [fractal] deserves to be called 1.26."[4]

Figure 1 below shows the sort of fractal du Sautoy is talking about:

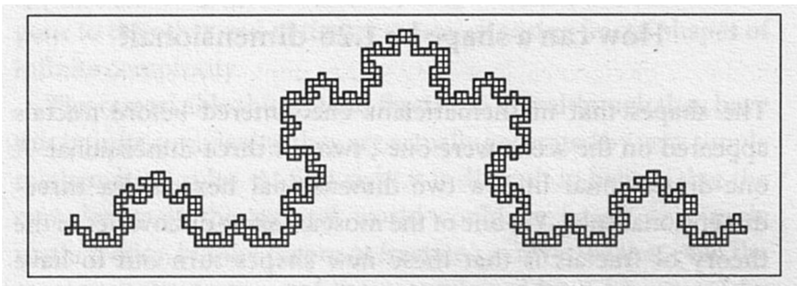

Figure 1 A fractal (from du Sautoy p. 94)

Here is the backbone of du Sautoy's argument:

Premise 1: A 1-dimensional object will cover 2^1 more overlaid squares if the squares are halved in size.
Premise 2: A 2-dimensional object will cover 2^2 more overlaid squares if the squares are halved in size.
Premise 3: Therefore, if an object covers 2^n more overlaid squares if the squares are halved in size, then it is an *n*-dimensional object.
Premise 4: The fractal being considered covers $2^{1.26}$ more overlaid squares if the squares are halved in size.

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Therefore this fractal has a dimension of 1.26.

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3. http://www.simonyi.ox.ac.uk/aims. Viewed 15 January 2012.
4. ibid., p. 95.

What du Sautoy has done here is disregard a fundamental tenet of the scientific method, namely, that if an observation repeatedly contradicts a hypothesis, you throw out the hypothesis. This somewhat obvious tenet is the cornerstone of all science. But du Sautoy's—at least with this example—keeps the hypothesis and redefines *dimension*. The hypothesis is premise 3 above and the definition of *dimension* that du Sautoy abandons—at least here, for he returns to it two sections later—relates to the number of values needed to define any point in that dimension. On the two-dimensional Cartesian plane, any point can be defined by its distance from two orthogonal axes. For example, a point on a parabola can be defined by the set (2, 4), which means that the point is 2 units along the x axis and 4 units along the y axis. Similarly, a point in three-dimensional space can be defined by a set of three values, each representing the distance from an arbitrary origin along each of three planes.

Now it should be clear that any point on du Sautoy's fractal in Figure 1 can be defined by two values in exactly the same was as any point on a parabola (or any point on the two-dimensional Cartesian plane). For that reason, we would call it a two-dimensional object just as we call a parabola or square a two-dimensional object. That is the common meaning of *dimension* and the one that every mathematics teacher teaches in the classroom. What du Sautoy should have done is declare that premise 3 is false: there are some two-dimensional objects that do not cover twice as many squares when overlaid with squares half the size. In other words, the fractal under discussion disproves the hypothesis.

A parallel should make clear du Sautoy's definitional slight-of-hand. Suppose our hypothesis is that water boils at 100 °C and we have observed this a number of times. We then go on a Himalayan trek and discover that, near Katmandu, liquid we thought was water boils at 94 °C. Wouldn't it be somewhat odd if, rather than revisit the hypothesis, I redefined *water*. Water [read *two-dimensionality*] is no longer H_2O [defined by the number of values needed to describe any point in two-dimensional space] but a liquid that boils at 100 °C [but an attribute such that it covers twice as many squares under some condition that I have pulled out of the air]. We abandoned—or rather, qualified—the water-boiling hypothesis because we now know that air pressure affects boiling points: the higher the altitude, the lower the boiling point. That is the scientific method at work. To redefine a well-entrenched mathematical concept—dimension—because it fails to meet a concept you are toying with smacks more of Aristotelianism than Baconism.

Later in *The number mysteries* du Sautoy ponders why the number of lemmings—those furry Arctic rodents prone to mass suicide, as folklore would have it—seems to plummet every four years. He explains this sudden depopulation with mathematics, but here again there seems to be some sleight-of-hand at work:

> "We start by assuming that, because of environmental facts such as food supply and predators, there's a maximum population that can be sustained. We'll call that *N*. We'll say that *L* is the number of lemmings which survived from the previous season, and that after the births in the new season, the population rises to *K* lemmings. A proportion of these *K* lemmings will not survive. The proportion that dies is *L*/*N*, namely the number of lemmings in the previous season divided by the maximum population possible. So *K* × *L*/*N* die …"[5]

And on the basis of this set of assumptions, du Sautoy proceeds to derive a simple formula to help explain the lemmings population at various times. Now this formula might well explain what it sets out to explain, but the derivation is certain to leave some readers suspicious. If I have 5 mice in a cage that could accommodate 50 mice and 1 mouse dies during some pre-defined period, are we to believe that the "proportion that dies is *L*/*N*, namely the number of [mice] in the previous season divided by the maximum population possible"? This would make the death rate 5/50 or 10%. Surely the death rate is the number of deaths per *actual*

5. ibid., p. 272

population: 1/5 or 20%. This is the common-or-garden, dictionary definition of *death rate*. The impression one is left with is that du Sautoy has engaged in some imaginative over-simplification in order to derive a formula that will nicely explain fluctuating lemming populations. But this only succeeds if a term is redefined in an unintuitive way (just as in the case of *dimension* discussed above).

Du Sautoy is not alone among scientists and mathematicians in playing loose with language. Whoever gave *chaos theory* its name certainly wasn't concerned with common-or-garden dictionary meanings. The Oxford, Macquarie and Webster's dictionaries all give much the same definition of chaos. Here is Webster's:

> "a state of things in which chance is supreme : nature that is subject to no law or that is not necessarily uniform … a state of utter confusion completing wanting in order, sequence, organization, or predictable operation"

This description is as diametrical to the systems that physicists call chaotic as one could imagine. So-called chaotic systems are strictly deterministic, but they are so complex that it is difficult, if not practically impossible—but not impossible *in principle*—to make long-term predictions about them. (The weather and the stock market are considered chaotic systems.) What defines them as chaotic is that minute differences in conditions at one time can result in states that are vastly different at another time. But this is not how the ordinary person understands *chaos*. *Complexity theory* might be a term closer to what chaos theory describes.

Another word rendered almost unrecognisable in the writings of scientists is *universe*. The Macquarie dictionary neatly sums up its common-or-garden meaning:

> "all of space, and all the matter and energy which it contains; the cosmos"

Thus talk of *multiverses* makes little sense to most people. Likewise, the following heading in *New Scientist*:

> "What the universe before ours was like"[6]

Whatever was *before* our universe—whatever that might mean—was still *the* universe. Further, there may well be pockets of the universe where the laws of nature differ, but to call each such pocket a *universe* is to blur meaning. It is also of blurring meaning to assume that the remnants of the big bang that created the earth constitute one universe among many. There may well have been other big bangs—well beyond our speed-of-light-limited event horizon, and thus undiscoverable—but they didn't create their own universes. They are all part of the one universe. By definition.

This is not to deny that common-or-garden views about the universe can't be wrong. They often—indeed mostly—are. The point is that you risk communication breakdown if you use a common-or-garden *word* to describe things that are sharply at odds with the common-or-garden *denotation* (and sometimes just the connotation) of the word. Chaos cannot be disorder and order at the same time; the universe cannot be the whole and a part at the same time. Black cannot be darkness and lightness at the same time. What is needed are new words for new things (as occurred with *quark* and *boson*). Old words for new things create ambiguity and cognitive dissonance. A rich language has *discrete* words for the distinctions and discriminations its speakers need to make. Some semantic multiplicity is acceptable, especially when each meaning can calmly sail by on a sea of context. But when semantic multiplicity includes contradiction—order and disorder; whole and part—communication is fraught.

Which brings us back to the perils of popularising science. Popularisers want to communicate with readers. Nobly, they want to share their erudition and passion. But they risk failure if the language they choose is at odds with the language of those they are seeking to communicate with. There may be no communication or, worse still, miscommunication.

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6. *New Scientist*, 12 April 2008, p. 10.

Miscommunication is grist to the mill of the science-sceptic. A lazy, near-enough statement—stripped of qualification and couched in terms that could imply the opposite—will be seized on by the radio shock-jocks, and the faux-experts who offer comment for cash, as evidence of doubt or, worse still, conspiracy. It might also be seized on by the growing band of anti-science politicians worldwide.

Finally, if science popularisers want to inspire the interested young to follow in their footsteps, it might be wise to remember that the interested young reading their book will no doubt have an above-average intelligence. A dullard is unlikely to buy a Hawking or a du Sautoy book. Thus there is a good chance that sloppy logic and definitional sleight-of-hand will be spotted. Some readers might consider it paternalistic (or writing down to the audience). Others might see it as laziness. Still others might think it an unintentional flaw. Whatever interpretation, the standing of the author—and by association, the author's field—is in some way diminished. And if the reader happens to be a science-denier with access to a microphone or the opinion page of a newspaper, the damage wrought could be far more substantial. At a time when science is under attack, communicative precision and logical precision is vital. Our future depends on it.