The use of figurative comparisons and analogies for science concepts

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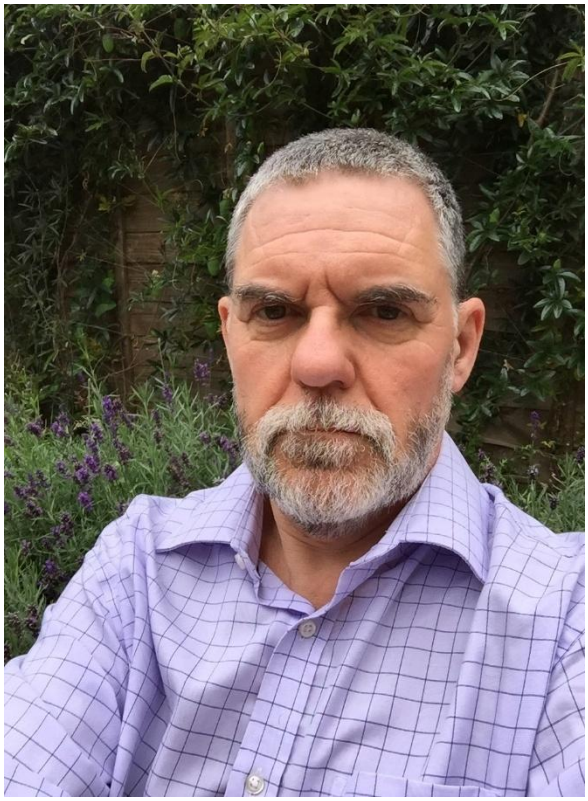

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Introduction

I have recently shared on my website a collection of quotes, from various sources, compiled into a document entitled '*Creative comparisons: Making science familiar through language*' and described as '*an illustrative Catalogue of figurative comparisons and analogies for science concepts*'.[1]

This document (henceforth, *the Catalogue*) offers a diverse selection of examples from the range of ways people try to explain science concepts through language using analogies and various figures of speech. Such tactics *can be* very useful given that many scientific ideas are abstract and cannot be simply demonstrated. Whether an example is effective or not depends on the aptness of the comparison made, as perceived by the audience (readers or listeners), so it can be challenging to devise effective examples; especially when addressing a diverse audience. Moreover, inherently, an analogy or other comparison is not quite the same as the thing being explained, so such comparisons will 'map' in some regards but not others.

The use of such comparisons may be best seen as an introductory tactic, which is to be followed up in more detail once familiarity with the new idea is established. At least, that is the case in teaching; but this may not always be possible when examples are used in some forms of science communication (such as a one-off interview on a radio programme or podcast, or a brief news report or press release). There is also an important distinction

between whether the comparison being used is intended to offer a technically correct understanding, or merely to give someone a feel for the gist of an idea. Usually in teaching the intention is to provide some objective level of understanding, and not just a *subjective impression of making sense*. But a technically correct understanding may not always be the primary objective in some forms of science communication. The novelist, journalist and broadcaster Melvyn Bragg has suggested that popular science books may engage the general reader without leading to deep understanding:

> Fortunately – or perhaps as a consequence of the increasing fervour in the sciences – books began to emerge which unashamedly sought to engage the general reader. We might not understand the maths, or the physics, of the chemistry, or the statistics, but this did not matter. The explanations were often clear enough for us to hang on to something of the substance. By 'us', I mean non-scientists…[2]

In the Catalogue I make a number of distinctions according to the nature of the language used - for example, whether a comparison is made explicit, or is simply 'smuggled' in without being marked. In an introductory essay I explain the distinctions I am using to classify comparisons as simile, metaphor, and analogy, along with examples I have classified as anthropomorphism, teleology and personification. I also discuss boundaries and shifts between these categories. This opinion piece is drawn from that introductory essay.

Making the unfamiliar familiar

Communicating science involves making something currently unfamiliar, familiar. The speaker or author believes they know something the audience does not and seeks to communicate this idea so the audience will also know it. This is possible because people share language. But it is also sometimes problematic because no two people share *precisely the same* language - the same lexicon and set of meanings and nuances for words. It can be problematic because the specific meaning of a word is not simply available from a dictionary but depends on context - and often the communicator has a good more relevant context than the audience. It can be challenging because the speaker or author may be an expert communicating with non-experts and therefore trying to offer a glint of some idea which would not be accessible to the audience in all its technical glory.

A key aspect of teaching is making the unfamiliar familiar. In a sense, that is the job. Before teaching, the learner is not familiar with, say, electric field, mitochondria or ionic bonding, but - if all goes well - after teaching the learner has become familiar. We would probably aspire to say they have acquired the concept or understood the idea being taught. Sometimes it is relatively easy to familiarise - we can hand a pipette to a learner and ask them to use it; we can pass around samples of different rock types. Sometimes we can use various types of models and representations. There are challenges in using models (do we use an NaCl model with space filling spheres, or one with 'straws', or both to help avoid the model being understood too 'concretely'?): but they are valuable tools.

Yet there are lots of things to be taught that are not so easily introduced - black holes cannot be passed around the room, and nuclear fusion cannot be demonstrated directly. There is a key role, then, for language. Some of this is straight-forward description - but there are plenty of things that cannot simply be described by using adjectives such as large, red, shiny, smooth, soft, and so forth. A black hole is not *just* something distant and black.

Lavoisier noted that "comparisons with sensible objects are of great use in assisting us to form distinct notions of abstract ideas".[3] In practice, science teachers and other communicators commonly use comparisons, suggesting that this unfamiliar thing you need

to know about *is a bit like* this more familiar thing you already know about and are comfortable with. This is seldom sufficient, but is a starting point; *introducing* the unfamiliar concept so that it is 'anchored' to what the learner finds familiar, and provides a base from which to develop understanding.

Making the unfamiliar familiar by comparing it with what is already familiar relies on the speaker/author knowing what will be familiar to the audience. This can be misjudged sometimes so the comparison is not especially (or at all) familiar to the audience. Or, perhaps worse, is itself misunderstood. There is little merit in learning that heat flow is somewhat like the flow of electricity if one has fundamental misconceptions of the nature of electric current.

This also means the effectiveness of a comparison may be relative to a certain audience, and may not transfer well, for example, to a different cultural context. Some historical examples now seem very unhelpful.

Familiarity through representation

People are often only familiar with something because of being introduced to it through representations. These may be photographs or movies (how many of us have actually seen a nuclear bomb explode, compared with how many of us have seen films of such explosions? How many of us have seen people walk on the moon?) Sometimes these representations may be models of some kind, or even narratives.

For example, medical anthropologist Theresa MacPhail compares the histamine cascade to a nuclear chain reaction, which she assumes is familiar to her audience, as: "*we've all seen that nuclear reaction example with the ping-pong balls, that's a bit what it's like with histamine. So, once one ping-pong ball goes off, the cells next to it get the signal*…". I suspect the common experience here is not a nuclear chain reaction itself, but the *modelling of* the process used in Walt Disney's film '*Our Friend the Atom*' where table tennis balls attached to mousetraps (as neutrons in atoms) are used to demonstrate a chain reaction.

If a learner or audience member is being referred to a comparison which is only familiar in this way, then the transfer of some idea from comparison to target obviously depends on the quality of the *representation* in relation to the focal point being presented. The relevant point has to have been represented in the model; has to have been salient enough for the viewer/reader to have represented it in memory; and has to be recalled as relevant when the comparison is 'made sense' of. (I wonder how many people remember seeing the footage of those table tennis balls 'flying' around, but could no longer explain what they were meant to demonstrate?)

Not that I am suggesting such representations necessarily lack the potency of direct experience. As one telling example, Charles Darwin explained the appearance of some fossil trees he saw in South America using the simile that they were *like Lot's wife*. I have previously noted that:

> I think this is an interesting example because it shows us that Darwin was confident that his correspondents would be familiar with the story of poor Lot's wife (who tends to only be known as a 'plus one'). As he was writing to a university Professor who had to be an ordained Church of England priest to quality for his teaching post, this seems a fair assumption. Henslow shared Darwin's letter with members of a scientific society, who would all also be assumed to be familiar with this story. I am not sure how true this would be today?
>
> However, I would also point out that neither Darwin or Henslow nor indeed anyone else alive at that time had ever seen Lot's wife, either before or after she became collateral damage in what was supposed to be God's imprecisely targeted wrath.[4] I guess that in the days before television, personal computers and mobile phones, people had to create their own

> entertainment by imagining scenes of death and destruction they read about for themselves. That is a slightly cynical point, but I do suspect that for Darwin and Henslow, and their discourse community (but not for many people in large parts of the world today), a reference to Lot's wife would likely bring a very specific and vivid image to mind. Otherwise, the simile has no value. [5]

Clearly a comparison which is understood by people in one cultural group may not make sense to those from outside that group. Elsewhere in his writings Darwin suggests that certain cells when immersed in acid come to "look like ghosts" - presumably assuming his readers share his own mental image of the appearance of ghosts, and again, as with Lot's wife, one might question the basis of such an assumption.

Darwin also compares the shape of part of an orchid to being like the mouth of a decoy - a reference that may not make sense to people who do not engage in shooting ducks. When astronomer/cosmologist Fred Hoyle referred in his popular writings to the Red Queen, or the King's Men, he seems to have assumed his readership would be familiar with Lewis Carrol's 'Alice' books. Perhaps he judged this correctly, but using such cultural references risks obsolescence (something I quickly learned when a school teacher).

I am old enough to know what is meant by saying that the patterns found in some brain scans looked like "*Captain Scarlet's Mysterons*", but perhaps that would not be so with younger readers of the 2017 book offering this simile?

We are only a couple of generations from when any English professional man (sic) writing for the educated classes could simply assume audience familiarity with the writings of Homer and Ovid and other classical authors, and references to Procrustean beds, Protean forms, and the like would be immediately understood. I am not sure authors of popular science works could safely make such assumptions now. I *assume* the reference to Helen in a 1995 book suggesting that chemical synthesis leads to 'a chemical Helen' is to Helen of Troy, supposedly the most beautiful woman of her time and the cause of, well, much trouble in that city - but, even if I am correct, I also wonder if the reference would have mystified some readers.

Scientific accuracy

Inclusion in the Catalogue is therefore not intended as a recommendation of the validity or pedagogic value of the comparison being made, nor of the accuracy of the science described. The Catalogue provides examples of practice (in communicating and explaining science), without evaluations (which would need to be audience-dependent in any case). For example, I include an analogy where the development of the eye lens is compared to that of an onion bulb, making the point that both grow in layers from the inside out. Yet an onion bulb actually grows outside-in: new layers develop inside existing ones.

Nigel Calder refers to a historical notion that when a comet moves through space it will disturb the æther as a ship disturbs the sea it passes across. For many centuries it was believed that the heavens (from the moon outwards) were made from a quintessence, a 'fifth' element (other than earth, water, air and fire); and later it was assumed that something (the luminiferous ether) filled all of space and acted as the medium which oscillated when electromagnetic waves were transmitted through it.

The idea was slowly dropped when it was realised the ether was not only undetectable but was not needed - but Calder is reporting an analogy which would have made good sense at a time when æther *was* widely accepted. So, when, in 1830, John Herschel wrote that there is an analogy between sound and light, he was correctly reporting scientific thinking of his time that the "common phenomenon" was "the vibratory motion of an elastic medium".

Another historical example is offered by the physician and naturalist Thomas Gough

(1805–1880) who in comparing the ability of a blind person to safely navigate the street (which he puts down to the sensibility, *i.e.*, sensitivity, of the person's face in detecting approaching obstacles) to that of a bat that can fly in the dark. Thomas refers here to the "*fine mesh-work of nerves in the Bat's wing, which enables the creature, in the dark to find it's [sic] way*…" This is in the context of discussing the life of his father, John Gough (1757 -1825) who despite being blinded by smallpox as a young child was an active natural philosopher and, in particular, botanist.

Father John himself was closer to the *now accepted* explanation of bat's navigation when he suggested that the bat used its senses in the way he had trained his hearing to enable him to find his way around in familiar streets from the sounds reflected from walls and other objects.

Context

Inevitably, most of the quotations in the Catalogue are short extracts from longer, sometimes *much* longer, texts. It would therefore be wrong to assume one can always judge the likely effectiveness for communicating scientific ideas from these examples in isolation, as sometimes what is presented here was originally embedded in a larger text that provided context for making sense of the extract. Clearly, once an author has explained something in depth, they may later refer to it more obliquely, and summarily.

For example, consider this extract (with emphasis added) which is the conclusion to a popular science book,

> Our everyday world, plainly *moulded* by subatomic forces, also owes its existence to our universe's *well tuned* expansion rate, the processes of galaxy formation, the *forging* of carbon and oxygen in ancient stars, and so forth. A few basic physical laws set the 'rules'; our emergence from a simple Big Bang was sensitive to six 'cosmic numbers'. Had these number not been '*well tuned'*, the gradual *unfolding* of *layer upon layer* of complexity would have been *quenched*. Are there an infinity of other universes that are *'badly tuned'*, and therefore *sterile*? Is our entire universe an '*oasis*' in a multiverse? Or should we seek other reasons for the providential values of our six numbers?

There is a high 'density' of figurative language here. Perhaps, so much that it could overwhelm a reader: certainly, when presented like this. But *in the context* of the wider text, this passage reviewed and reiterated ideas that had been treated in some detail earlier in the book. To fairly judge whether the figures of speech used here are effective in communicating meaning to readers, one should investigate what people reading the whole text made of this extract when they got to the end of the book. [6]

Consider, also, Kit Chapman's suggestion near the end of the book *Superheavy* that "the heavy element community weathered the greatest storms of the twentieth century and kept on building *the jigsaw of our world*". The jigsaw reference seems to be a metaphor. It refers to the periodic table. Chapman had, earlier in the text, used an analogy that Mendeleev's achievement in producing the periodic table was "the equivalent of putting together a globe-spanning jigsaw puzzle without knowing the picture, the shape or how many pieces came in the box". The passages are separated by over 260 pages. So the context is there, but a reader has to have read the earlier passage *and* retained the association if they are to recognise how 'jigsaw' is being used.

Some less 'transparent' metaphors or similes may deliberately be used to engage (and

perhaps intrigue) the audience, but then be followed-up by text which develops the ideas initially alluded to only figuratively. For example the biologist Ludwik Fleck, in a nature of science case study detailing the development of a serum test for syphilis suggested that "*For Wasserman and his co-workers shared a fate in common with Columbus. They were searching for their own 'India' and were convinced they were on the right course, but they unexpectedly discovered a new 'America'.*"

In itself this seems to be an extended metaphor - we are told what the situation was like, but not what it was. Fleck continued: "*Nor was this all. Their 'voyage' was not straight sailing in a planned direction but an Odyssey with continual change of direction*." So, the research was a bit like Columbus discovering America by accident, but *also* a bit like the long, indirect, oft-interrupted, voyage of Odysseus (Ulysses) as he made his way home from the Trojan wars (yes, another classical reference). So, this seems a mixed metaphor.

However, Fleck then states that "*What they achieved was not even their goal"* as "*They wanted evidence for an antigen or an amboceptor, Instead, they fulfilled the ancient wish of the collective: the demonstration of syphilitic blood*." This maps to the India/America metaphor, making the reference into an analogy. (I discuss how I am using the categories of metaphor, simile and analogy, to classify examples, below.)

These reservations certainly apply to some of the necessarily limited extracts offered in the Catalogue (though there are also many examples where I did not spot any such supporting context). As one example: what is to be made of the suggestion that a naturalist might spend his time "*employed in extending his acquaintance [with nature] and familiarising his finger with the ornaments of her temple*"? This is an example of how it was once common to personify Nature as a woman. The reference to "*familiarising his finger with the ornaments of her temple" could* seem to be some smutty attempt at innuendo. However, when the description relates to the blind naturalist (John Gough, see above) who, it had been explained, would use his fingers to study animals and plants in great detail, this term – still rather poetic to modern ears – seems less like a double entendre.

Translation

The Catalogue includes quotations from texts which have been translated from other languages. Translation between natural languages is never simply a technical process, but rather requires considered choices. [7] Effective translation is a skilled but also a creative process. Translated texts should therefore never be assumed to be the work solely of the translated author - and translations may suggest nuances which would have been less obvious or even absent in the original. With historical texts, there may be multiple translations made at different times, each somewhat reflecting the contemporary cultural milieu of the translator. There is clearly a question for a translator of whether they are trying to preserve the original cultural context as much as possible, or rather looking to phrase material in a way more accessible to a modern readership.

Consider:

- "The earth moreover is fertilised by the sun and conceives offspring every year." (tr. Charles Glenn Wallis, 1952)
- "Meanwhile the earth has intercourse with the sun, and is impregnated for its yearly parturition" (tr. Edward Rosen, 1978)

Nicolaus Copernicus was writing in the sixteenth century, and in Latin. Neither of these statements 'are' what he 'actually' wrote [*i.e.*, "*Concipit interea à Soleterra, & impregnatur annuo partu*"]. Both are attempts to translate his text into English. While they certainly reflect the same basic idea, the different choices of wording give a somewhat different impression and it would be generous to suggest they have precisely the same meaning. In reading quotations in translation

(as sadly many of us have to do) it is useful therefore to bear in mind that one is not dealing with the text of author Y, but with translator X's rendering of author Y.

Analogies, similes and metaphors

Comparisons vary considerably in nature. One useful categorisation is to consider many of these comparisons to be analogies, similes or metaphors. The distinctions here are about the detail offered and the explicitness of comparison. I have borrowed the terms simile and metaphor from their use in discussing literature. A metaphor has 'hidden meaning' whereas a simile tells us something is 'like another'. An analogy goes beyond simile by detailing how/why the comparison applies. Consider as an example:

- the nucleus is the brain of the cell
- the nucleus is like the cell's brain
- the nucleus acts as the cell's brain
- the nucleus is the 'brain' of the cell
- the nucleus of a cell is like the brain because where the brain controls the behaviour of the body, the nucleus…

In the first case there is a suggested identity - the cell nucleus *is* a brain. But (presumably) this would not be meant literally, rather figuratively: it is a metaphor - the cell nucleus is (metaphorically) a brain. The audience member (a learner, a reader, a listener) is expected to appreciate that although they are told the nucleus *is* a brain, they are meant to read this figuratively as the nucleus is *in some way like* a brain. Readers or listeners may well often appreciate this. Sometimes, with some metaphors, some audience members may not.

A simile is distinct from a metaphor as it is made explicit there is a comparison being made. It is not an identity (a nucleus is a brain) but a comparison (a nucleus *is like* a brain). There are various ways this can be phrased ('kind of', 'sort of', 'as if'…), but the key thing is that the comparisons is marked. In one example above inverted commas are used as 'scare quotes' to indicate the term is not being used literally.

A simile tells us we a dealing with a comparison, although it may well be left to us to work out *why* the comparisons is like the target (*e.g.,* why a cell nucleus is considered to be in some way like a brain). An analogy goes beyond this by describing points of similarity. We say there is 'mapping' across from analogue to target. Of course, there must be something being mapped by an author when using a simile, but it becomes analogy when the mapping is made explicit. As an example of 'good practice' in being explicit when using an analogy consider the idea that a genetic mutation is "*a little like a mistake in a knitting pattern*". Biologist Nessa Carey, who uses this analogy in her book on 'Junk' DNA[8], maps out features of how she is using the analogy:

> …a gene (the knitting pattern) ultimately codes for a protein (the sweater). The DNA gene is the original knitting pattern. This pattern can be photocopied multiple times, akin to producing the RNA. The copies can be sent to lots of people who can each knit the same pattern multiple times, just like creating the protein…

This is how I am using these terms (metaphor, simile, analogy) here. Sometimes authors use these terms quite differently, for example referring to a comparison they have used as an analogy, when the comparison has not been mapped out (so, here, this would be considered a simile). Perhaps in some cases the analogy is explicit in the mind of the author, but it has not been shared through the text.

The philosopher of science Mario Bunge suggested, "metaphorically speaking, a scientific theory is *like* a mollusc with a soft core". As the comparison is made explicit, this would qualify at least as a simile by my criteria here. However, Bunge then went on to specify *how* he thought a theory is like such a

mollusc, promoting the comparison (in my scheme at least) to an analogy.

Although it may not seem *that important* whether a comparison is labelled as a metaphor or a simile, for an educator I think there is an important difference as similes are *presented as* comparisons, whereas metaphors are not marked as such.

Metaphors

Metaphors, then, put a greater burden on the audience. The reader or listener first *has to realise* that a term is being used figuratively and does not have its usual literal meaning; and then has to work out what the point(s) of comparison are. Clearly using metaphor is not ideal when explaining science. So, we might expect there to be limited use of metaphor in science texts. Yet, actually metaphors are very common in some popular science books and in broadcast accounts of science. As some of the examples detailed in the Catalogue suggest:

- black holes may be hairy
- brain-blood barrier is great wall of China
- comets jaywalk across the paths of planets
- data should be cooked with care
- digestive enzymes are biological jackhammers
- heating causes similar particles to dance together
- inner Solar System is a cosmic billiard table
- Kohouteck was a virgin comet
- lipids have split personalities

The ubiquity of metaphor in science communication might seem strange, except that metaphor is such a central feature of natural language.[9] There is a scholarly argument to the effect that much of our learning is *necessarily* metaphorical as we draw on direct experience of the world. In everyday discourse we often automatically make sense of metaphor we encounter without any conscious analysis. But perhaps when we are communicating for pedagogical purposes, to explain some science, we should want the audience to notice, question, and reflect on the meaning of such comparisons?

Dead metaphors

In one of the extracts listed in the Catalogue, geneticist Steve Jones suggests that "*Information is transferred by gene in much the same way as it is by words. For each, evolution is inevitable…*" Natural language often 'evolves' through metaphor. A term which means one thing becomes used metaphorically to convey another meaning, and, if this seems apt to enough people, the usage may spread and become conventional usage after a while. The term 'charge' to mean electric charge was introduced as a metaphor from the charge used in a weapon such as a musket. Today electric charge is an accepted term, and most people are more likely to associate charge with electricity than the source context of firearms.

William H. Donahue notes that Johannes Kepler changed the usage of the word 'orbit'. It had originally referred to the track left in the dirt by a wagon wheel. The apparently complex 'wanderings' of the planets were labelled as 'orbits' - *i.e.*, as a metaphor. Kepler kept the term, but in his system an orbit was no longer wandering, but was "a fixed, closed path in the heavens, which a planet traverses repeatedly".[10] That is, a 'live' metaphor can, over time, become a dead metaphor which is then just an everyday word.

Metaphors are only alive or dead in a metaphorical sense, but the term 'dead metaphor' is now so well established is may itself be considered a dead metaphor. There will always be a transition period as the term shifts into general use, but - eventually - the new meaning is literal as it will be represented in dictionary definitions and will be met as part of normal first language learning.

In 1665, Robert Hooke somewhat anticipated the idea of zero point energy (though clearly not based on modern ideas of quanta) by suggesting that the particles in a body are *never at rest, or lazy*. 'Lazy' here is clearly an anthropomorphic metaphor as molecules (in today's terms) do not move (or not) as a matter of volition, so cannot be lazy. By contrast, the suggestion that particles may be 'at rest' adopts a term widely used today to mean stationary and does not immediately strike the reader as figurative. However, particles do not rest, or need to rest (or, indeed, *if* lazy, rest when they do not *need* to!), so surely this was also *originally* a metaphorical reference, which has now been a dead metaphor for so long that it is simply now a 'technical' term with the literal meaning of not moving.

It seems reasonable to suggest that when new terms are introduced metaphorically into a specialist field because they reflect the need to describe some new phenomenon or concept (which is therefore likely to be of interest to others working in the field), and this is taken up as useful by others, the terms will likely enter into common usage, within that field, relatively quickly. I would conjecture therefore that discipline-focused metaphors will, when adopted, move into wide use within technical discourse much more quickly than tends to happen with metaphors becoming accepted terms in a broader natural language.

If this (reasonable, surely) conjecture is correct it adds to the challenge to the general reader looking at technical literature as such 'phantoms' are not only part of a specialist lexicon but may become established within the disciplinarily discourse relatively rapidly.

Idioms

Idioms can be seen as metaphoric, as like metaphors they have a figurative meaning. What makes them somewhat different is that they are widely used as taking a *particular,* if still quite general, meaning. This has the advantage that a reader or listener is likely to recognise an idiom and to appreciate its general sense. So, when something is said to be 'on steroids' (be it the climate, or tandem repeats within 'corners' of a genome, as in examples included the Catalogue) this *is* metaphorical, but is now such a widely used metaphor as to be idiomatic (with a similar meaning to another idiom of 'going into overdrive' - as the immune system and gravity are said to in other entries).

Sometimes idioms are unmarked as metaphors, as when viruses "*go on a rampage*" or proteins on cell membranes "*put the brakes on immune responses*". However they may also be used as similes as when the "*unvaccinated population <u>were like</u> fish in a barrel for the measles virus*" or"*Ceres and Vesta <u>are like</u> chalk and cheese".*

A particular concern with the use of idioms in science communication relates to second language users, as idioms tend to be idiosyncratic to particular languages, and so may lose their meaning on translation. Where an idiom has a conventional range of use without an obvious derivation (it is 'raining cats and dogs', anybody?), a non-native speaker who is not familiar with the idiom may struggle to appreciate how it is being used, and will not even know it is idiomatic.

Anthropomorphic language

In the Catalogue I have categorised separately examples of metaphorical language I consider to be anthropomorphic. Anthropomorphism is the assignment of human features to non-human entities. Humans can desire, hate, regret, think, evaluate, etc. Rocks cannot. Nor can atoms. Yet it is extremely common for atoms to be said to need or want, and even to be happy or unhappy.

It might be argued that in many of the examples included in the Catalogue, it is 'obvious' how the anthropomorphic statement should be read figuratively and so interpreted in terms of valid scientific concepts. I am sure this is true for the expert reader or listener. The extent to which this is also the case for

non-specialist, I would suggest, is an empirical question.

I have also included examples where phrasing suggests something is an active agent where from a scientific point it is clearly passive (*e.g.,* "… those *electrons will arrange* their spins in opposite directions"). As an example of the distinction I am highlighting here, consider this passage:

> *The regular polyhedral shape allows the proteins that clad the viruses to pack themselves in the most economical way around the central volume containing nucleic acid*. This coating would tend to form as a flat hexagonal sheet of interlinked protein molecules, but for surface tension effects of the plasma membrane that encases the nucleic acids which force the sheet to accommodate pentagonal units such leading to its closure into a polyhedral cage. [11]

The second sentence here reflects the traditional passive voice of science for describing physical phenomena : "tend to form…surface tension effects…which force the…leading to…". Here we have mechanisms due to forces acting. However, this is proceeded by a sentence which seems to suggest an effect can be explained by the action of virus proteins that have been 'allowed' '*to pack themselves'* in a particular manner. This sentence can easily be read (and likely would be read by professional scientists) as simply explaining how geometry links to energy minimisation: but would non-scientists be more likely to see this as an active (and implicitly deliberate) deed where proteins are not mindlessly packed together by the forces acting between molecules, but rather have, as reported, 'packed themselves'?

After all, if the custom officer asks if you have packed the bag yourself, she is asking about your deliberate and conscious actions that you can be legally held accountable for. The two contexts are very different of course, but we can only read information from contexts we are already sufficiently familiar with. My question is always *'what would the non-expert understand by that?'*

Personification in science

It was once traditional to personify Nature, applying the pronouns 'she', 'her' and so forth. Although this is a poetic trope, it was adopted by some early scientists and is still sometimes seen in modern texts. The personification may be limited to the use of pronouns, but sometimes is combined with other metaphorical language - as when Robert Hooke advised that scientists (to use our modern term) should "trace *her steps*, and be acquainted with *her manner of walking* there, before we venture our selves into *the multitude of meanders she has* in bodies of a more complicated nature". Nature cannot walk, but Nature personified is described in these terms.

Although Nature is widely personified, she is not alone. Indeed, as I was compiling the Catalogue, the US government's Department of Energy decided to personify coal to make her [sic] seem more attractive as fuel for power generation: apparently "she is the moment".

Teleological phrasing

Teleology is about purposefulness. Scientists who report that they boiled a solution *to* kill any bacteria present are simply reporting what they did and why. However, from a scientific perspective, natural mechanisms do not reflect purposes. There is a lot of teleological language used in discussing science. This is especially so in the life sciences. This is understandable, as the central explanatory framework for much of biology is evolution, and natural selection leads to highly complex adaptations which can *seem* purposeful and, moreover, can be more easily discussed using the notion of *functions*.

For example: *the function of the heart is to pump blood around the body*. That seems very reasonable, but the heart has evolved to

do this through natural selection, and was not deliberately designed in the way a central heating pump was designed to pump water around the central heating circuit.

Catherine Carver writes about an ectopic spleen as a spleen being *in the wrong place* due to something having *gone awry* during development. This language make perfect sense if we consider *normal* to be natural and right. The spleen is (in this language register) *meant to b*e located at a particular place in human anatomy, and there is *a proper and correct* developmental process that usually ensures this. But strictly this is teleological. This seems akin to a naturalistic fallacy - that we can judge what is good and right in terms of what is found to occur in nature.

Taking an evolutionary viewpoint suggests that variations and even mutations that produce individuals who are abnormal in some way, though often unfortunate for the individual, are absolutely essential to the diversity of life-forms on earth. If normality were *more than* the norm, and became a universal, then no one would have spleens as we would all still be, at best, single-celled organisms. From a biological perspective that acknowledges evolution, an ectopic spleen is a spleen being *in an unusual place* due to something having *gone differently* (not wrong) from normal during development. Comparing any species alive today with its distant ancestors will suggest that what is normal today was atypical once, and never existed even earlier.

Describing biological functions in concise language can almost inevitably lead to teleological phrasing. So, for example, *immune cells send out antibodies to kill pathogens*. This seems to imply a purpose which would in turn seem to suggest some kind of deliberate design: pathogens need to be killed, and antibodies are constructed to do the job. Body cells want pathogens dead (anthropomorphism) - and they work towards to this aim by producing antibodies.

This narrative is strictly unscientific, but it is much easier to produce than to say something along the lines that *plasma cells have evolved over a great length of time to secrete antibodies which (through selective processes) have properties that led to the destruction of many pathogens*. Immune cells tend to release antibodies in contexts where there are pathogens, and the antibodies tend to damage those organisms; and this is not just a lucky chance - but nor is it purposeful. It is what has evolved through myriad interactions in a system of interacting complex organisms.

Teleological language may overlap with anthropomorphism. To suggest that apoptosis involves cells "*dying at the right time, cells inside bodies sacrifice themselves for a higher good*" seems to both suggest that the cells die for a purpose, and that the cells themselves are active and willing (*sacrificing themselves*) participants. I have included examples where I felt the wording could imply a situation existed or a change occurred to meet some end or for some purpose. The teleology might be intended - so Hutton's views of volcanoes was founded on a belief that the earth had been designed to be suitable for life-forms, and might be considered to reflect the broader natural theology perspective that sought to explain nature in terms of the creator's purposes.

But I have also included examples where I assume the author would not commit to a teleological perspective, but their words could be understood that way. For example, Natalie Starkey is a contemporary science writer, and I imagine assumes the world can be explained in terms of natural properties and mechanisms. Yet her explanation of how platinum group elements (PGE) moved towards the earth's core because of these iron-loving elements' affinity for iron seems to suggest, at least, something occult:

> ruthenium, rhodium, palladium, osmium, iridium and platinum…are siderophile elements, meaning they are 'iron-loving'…The PGEs' affinity for iron means that, when the Earth formed, they tended to preferentially gravitate towards the Earth's core because it is itself made mostly of iron.

From an educational perspective, the potential problem with teleological phrasing such as *immune cells send out antibodies to kill pathogens* is that *because* the language *suggests* purpose it is very easy for novices to interpret the phenomena that way, rather than realising that although we may see 'functions' everywhere in biology, Nature herself [sic] is 'blind' to this and has no intentions or aims.

Simile

I am distinguishing similes from metaphors by the presence of explicit markers that tell a reader or listener that a comparison is being made:

- "…this sort of swirling maelstrom…"
- "…they are like harpoons or missiles…"
- "…this was the 'ethnographers's magic'…"
- "…as though a rope had been twisted round them…"
- "…a protective jacket if you like…"
- "…as if the bases were holding hands…"
- "…the two black holes kind of sink slowly…"
- "…fly apart as though they were a flock…"
- "…slip in unannounced if you see what I mean…"
- "…they, so to speak, eat their way…"
- "…furnished biology with an Archimedean fulcrum, as it were…"

Although the term simile is usually used to refer to poetic comparisons, I am including examples of what I term *descriptive* similes used to communicate the appearance of something (assumed to be) unfamiliar to the audience by comparing it to the appearance of something (assumed to be) familiar to the audience. The invention of the microscope revealed a realm of detail of things previously not observed.

In his *Micrographia*, Robert Hooke included verbal descriptions offering comparisons with the appearance of things Hooke assumed his readers would be familiar with. He describes the magnified appearance of a razor blade edge as "looking almost like a plow'd field, with many parallels, ridges, and furrows…". In a more recent example, in '*The Vaccine Race*', Meredith Wadman refers to how a virus left infected cells "looking like Swiss cheese". This likely presents a strong visual image for many readers.

Most of the similes included are more abstract and are drawing upon a specific feature or characteristic where a similarity is seen with something quite different. So, a crystal lattice, was said in one of the examples included in the Catalogue to be *like wall paper*. Where a comparison is not made explicit, the author is relying on either the readers' funds of background knowledge to find the relevant point of similarity salient, or upon background provided by the context within the wider text. All similes might then be seen as potential analogies, where the reader/listener can convert the simile to an analogy by recognising what the point of comparison is.

Analogy

Analogy has been used in science to develop concepts - for example in deciding that potassium and sodium should be considered metals by comparing their properties with those of previously familiar metals as the points of similarity were considered more significant than those of difference. [12] Perhaps it seems obvious now that these highly reactive, soft, readily melting solids should be classed as metals, but this is ahistorical. Likewise, to a modern reader there seems little of genius in Joseph Black being "*persuaded that in the same manner as ice, in liquefaction, requires the combination of a great quantity of heat, in order to form water, so water, in order to its conversion into steam, also requires another combination with heat*", as it is difficult to re-conceptualise

the world without those concepts (here of 'latent heat', now a technical term that was perhaps itself initially a metaphor) we have long ago learned and applied.

An analogy is in effect a comparison between two 'structures' or at least two foci that can be presented as structures. That is, it is *possible* to 'map out' the two structures as concept maps, and show the extent of mapping between the two strategies. In an oral presentation, and usually in written texts, analogies are presented in words, but to be an analogy the comparisons must show a similarity in terms of some kind of parallel between *relationships* in the two domains. A suggestion, by Neil Shubin, as concise as "*Genes are but islands in a sea of DNA*" can be considered an analogy as the structural similarity between analogy (islands in a sea) and target (genes in DNA) is clear.

Sometimes the parallel will be so strong that a better representation would be that as Z is to X, as Z is to Y. So, Prof. Stephen Kane of the University of California has compared the rings seen around some planets to the blood spatter on the walls of a crime scene because *both* are evidence that something catastrophic happened there. Analogy is often used to generalise beyond the data available in science, as in this example from Ernest Rutherford,

> An examination of the complex pencil of rays from a layer of radium in equilibrium shows no evidence of the presence of α rays which suffer an abnormal amount of deflexion. I think there can be no doubt that the α particles emitted from the various products of radium have an identical mass, but differ only in the initial velocities of projection. Although the mass of the α particles has been determined only a single product of thorium and actinium, *the analogy with radium would lead us to expect* that the α particle has the same mass for all the products of these substances. [13]

An analogy is usually only a partial mapping between two foci: that is there is positive analogy (where mapping works) and negative mapping (where it does not). In a teaching context it may be useful to map out the analogy using a table or diagram to help learners appreciate the different points of positive (and negative) analogy. Sometimes an author offers us both a positive and a negative analogy - as when the philosopher Ernst Cassirer argues that physics, or physical science, is like an organism - where a failure to function properly (i) *cannot* be addressed as a watchmaker who might proceed by dismantling the watch to inspect each part (the negative analogy) but (ii) rather a physicist must be like a physician who makes a diagnosis without dissecting the patient (the positive analogy).

Sometimes an analogy is used to go beyond being a way of introducing an idea that needs to be made familiar, and becomes a kind of framing device for developing material in a text. For example, Natalie Starkey suggests in '*Catching Stardust. Comets, asteroids and the birth of the solar system*' that she thinks of the Solar System as a city with different neighbourhoods and goes on to map features of the analogy. She subsequently returns to, and develops, the comparison in a number of places (e.g., "the real estate surrounding our average star") in her text. Some references in the book which might seem, if read in isolation, as stand-alone metaphors can be appreciated within this wider contact as an extension of this organising analogy.

Perhaps an extreme example is Catherine Carver's *Immune. How your body defends and protects yo*u where much of the book is organised around the idea of the immune system as some kind of defence force waging a constant war with various invaders or saboteurs. That, of course, is a trope that widely permeates popular discourse about medicine and disease – but an analogy, like any kind of model, is an imperfect and partial refection of its target: so there is a danger *if* the model comes to be understood *as* the target. Yes, *in some way*s our immune response is *like* the work of a state's security forces, but if we *only* think about it in those

terms our thinking will be constrained upon lines that limit our understanding.

I think a perusal of the range of comparisons presented in the Catalogue offers much 'food for thought' for anyone concerned with the communication and explanation of science.

Notes:

[1] Taber, Keith S. (2025) Creative comparisons: Making science familiar through language. An illustrative Catalogue of figurative comparisons and analogies for science concepts. This can be downloaded from the webpage https://science-education-research.com/publications/, or using the direct download link: HERE

[2] Melvyn Bragg (1998) *On Giant's Shoulders. Great scientists and their discoveries from Archimedes to DNA*. Hodder & Stoughton.

[3] Antoine Lavoisier (1790) *Elements of Chemistry. In a new systematic order, containing all the modern discoveries.* (Trans. Robert Kerr).

[4] This may seen an unfair rendering, as the story is often told as though Lot's wife was killed because she disobeyed the instruction not to look back when God sent down destruction from heaven to annihilate Sodom and Gomorrah. The poor woman had accompanied her husband on a hopeless mission to convert foreigners in a country renown for its sinfulness, lived in fear of the violence faced there, and finally had the indignity of seeing her husband offer their virgin daughters for rape as he judged this the proper thing to do rather than handing over house guests. She is then expected to leave all behind and flee the forthcoming inflagration as a matter of urgency, and (against human nature) not look back when the devastation occurs. To suggest she deserved punishment seems…harsh. I would love to know what Kierkegaard made of the story.

[5] Taber, Keith S. (2025) 'What's the point of explaining science in the public domain?' Seminar paper presented on-line to CRESTEM (Centre for Research in Education in Science, Technology, Engineering & Mathematics) at King's College London, 5th February, 2025. Available HERE

[6] Rees, Martin (1999) *Just Six Numbers. The deep forces that shape the Universe*. Weidenfeld & Nicolson. London. This example is discussed in some detail at: 'Layers of complexity in unfolding meaning in a popular science text: Looking for the dark matter of hidden meaning'.

[7] Taber, Keith S. (2018). 'Lost and found in translation: guidelines for reporting research data in an 'other' language' [10.1039/C8RP90006J]. *Chemistry Education Research and Practice*, 19, 646-652

[8] I've used scare quotes here as even if the introduction of the term junk DNA was assumed an apt metaphor because so much of the DNA in a genome does not code for proteins, it has since become increasingly clear that a considerable proportion of this 'junk' is functional in various other ways. Perhaps here we have one ramification of the effect of dogma in science, in relation to the 'centra dogma' of molecular biology that DNA codes for RNA which codes for proteins. See: Crick, F. (1970). Central dogma of molecular biology. *Nature*, 227(5258), 561-563.

[9] Lakoff, G., & Johnson, M. (1980). 'The metaphorical structure of the human conceptual system'. *Cognitive Science*, 4(2), 195-208.

[10] Translator's note: Johannes Kepler (1609) *New Astronomy based upon causes or Celestial Physics* (Trans. William H. Donahue, 2015) Green Lion Press.

[11] From Hugh Aldersey-Williams (1995) *The Most Beautiful Molecule. An adventure in chemistry*. Aurum Press.

[12] See for example, 'The Origin of a Chemical Concept: The Ongoing Discovery of Potassium', Chapter 5 in Taber, K. S. (2019).

The Nature of the Chemical Concept: Constructing chemical knowledge in teaching and learning. Royal Society of Chemistry.

[13] Present author's emphasis. Rutherford, E. (1906) The mass and velocity of the α particles expelled from Radium and Actinium. Reproduced in *Classical Scientific Papers Physics*, 1964, MIlls & Boon Limited.