What's the point of explaining science in the public domain?

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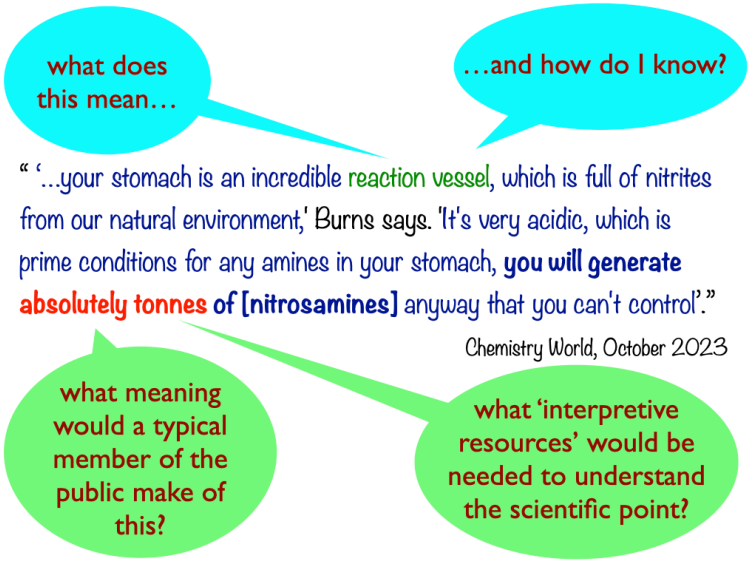
Abstract:

As a professional science educator, I have put a high priority on teaching for understanding. I always wanted my students to make good sense of the concepts being taught (be that force, bond, or later in my career, idiographic research). And despite having a healthy scepticism for the notion of canonical accounts of science (and even more so for any expectation that curriculum specifications could match such ideals), I have also seen objective understanding as the teacher's prior concern. It is good if Alice feels that she understands nucleophilic substitution, but ultimately she needs to be able to demonstrate that she can apply the idea in a way that matches an examiner's expectations. Recently I have been paying attention to the wide range of devices used by science communicators (scientists, popular science authors, journalists) to explain unfamiliar scientific ideas. In science teaching the familiarisation step (for example, perhaps referring to the nucleus of a cell as its brain), is seen as the starting point for developing a scientifically acceptable understanding. Subjective understanding - that is, feeling 'that makes sense' - is important, but not sufficient. But should that also apply to public science communication outside of education? This talk will present a range of examples of scientific ideas being introduced in these informal learning contexts - posing the question of what sense are readers/listeners meant to make of them; and the broader question of whether subjective understanding should be a sufficient target outcome in these cases.

Introduction

Good afternoon. Thank you for taking time to listen to me today. I am going to present you with some short extracts from examples of science communications of various forms that I would like you to interrogate.

In doing so I will offer some guide questions, and I very much look forward to your views at the end of the talk. However, I am going to start by setting out some background that offers a position from which to interrogate my examples.



'Science communicator'?

I want to begin by just suggesting how I will use the term 'science communicator' in an inclusive sense. So, among science communicators are:

- teachers, whether generalist teachers of lower ages asked to teach some science, specialist science teachers and lecturers from within more specialist science disciplines

but also:

- scientists writing for other scientists in research papers, monographs and review articles
- scientists, sometimes the same ones of course, writing or talking to more general audiences through talks, books, interviews, videos or whatever
- journalists who report on science,
- authors of popular science books, which may overlap with previously categories in that these authors may be scientists themselves or science journalists, but sometimes are in a somewhat discrete group of 'science writers' who specialise in 'trade' books
- as not everyone works with written texts, I perhaps need to also include the writers and producers of scientific documentaries and the like in case some of these people are not already found in my previous categories.

I should also perhaps include a group of people who are academics, and who write about science, but are not natural scientists themselves. These may be historians, philosophers, sociologists and the like. Their focus may not be the science *per se*. So, for example, the historian of science is looking to describe and explain history, not science, and may be more interested in a now defunct perspective or theory than current canonical understanding, but nonetheless may feel at some points a need to offer a scientific account as background for their argument.

Perhaps I should also include people like myself in this category, science educators, as sometimes in writing about the teaching of science it is appropriate to set out the science as background for making pedagogic points.

'Science communication'

I am going to make what I think is a reasonable claim, which is that, when such science communicators set about communicating science, an aim is, at least sometimes, to lead their audience to understand that science. That is, one purpose of the science lesson, or lecture; of the scientific paper, or monograph; of the news report, or science documentary; of the 'popular science' book; or the outreach talk given by a scientific researcher, is to facilitate members of an audience in coming to a new understanding of some science. In this sense, all scientific communication may be considered to have a pedagogic intent.

However, I would also like to draw a key distinction between two meanings or senses of 'understanding'. I am certainly not suggesting that these are mutually exclusive, just that they can be considered as somewhat independent of each other.

Objective and subjective understanding

I will refer to these two somewhat distinct foci as objective and subjective understanding. Subjective understanding is an internal thing. You read or her something. You may feel it clearly makes sense, and you fully understand it. Or, perhaps not. Perhaps it was completely, as the idiom goes, 'over your head' and you have not the vaguest idea what was meant. That is rare perhaps, but there are certainly shades of confidence one may feel in one's understanding.

objective and *subjective* understanding

- "I kind of know what entropy is, but I am not sure I have a full appreciation of the subtleties."
- "I have a qualitative feel for what the the Schrödinger equation is about, but do not think I could apply it."
- "I know the overall equation for photosynthesis, and understand the overall process; but I also understand that it is a multi-stage process, and I *know I do not know* the details of the different stages."

- n.b., metacognition is being used here to report subjective understanding

Now subjective understanding is perhaps more about feeling than thinking - or at least it seems to be largely informed by implicit knowledge. One comes out of a lecture or finishes reading a paper, and one has a feeling about the extent to which one had understood. I think subjective understanding is - initially at least - more an affective evaluation than a conceptual one.

By contrast, objective understanding is not about how well you feel you understand, but the extent to which you can demonstrate understanding to others against some community-agreed criteria. Teachers know all about this. Efforts are made to set up assessment activities which give a valid and reliable measure of whether the learners understand food webs, capacitors in parallel, or electrolytic cells. I should point out that often the key referent here is not current canonical scientific knowledge; but some curriculum model located at some turn of the spiral curriculum - which likely simplifies, and sometimes oversimplifies, the science.[1]

Correlation?

Anyway, I think to the questionable extent that it is meaningful to apply quantitative terms to a feeling like subjective understanding, there is likely to be a positive correlation between measures of these two forms of understanding. People are more likely to feel they understand something when (objectively) they do. People are more likely to be able to demonstrate objective understanding of those things they feel make sense to them.

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[1] That is important, but having noted that, I think we can bracket it away for present circumstances. After all, even current canonical science is no more than a particular account currently judged by the relevant sub-groups of the scientific community as our best partial account of some phenomena based on the data collected and analysed so far. I could go further than that - I have suggested elsewhere * that canonical scientific concepts are ideal referents but have no real content: perhaps like unicorns as difficult to exemplify in practice as the lady of leisure, the perfect gentleman, the ideal state, the perfectly equitable and just society, or full employment. [* see Taber, K. S. (2019). *The Nature of the Chemical Concept: Constructing chemical knowledge in teaching and learning*. Cambridge: Royal Society of Chemistry.]

Understanding

But those of you who are practicing teachers are likely to agree when I suggest that even if such a correlation is statistically significant it would not approach unity. We have all surely experienced learners who can regularly get high marks on questions about some bit of science that they persist in claiming makes little sense to them. That can be very frustrating as we cannot direct all such learners to scientific fields like quantum mechanics. Similarly, we have all had those happy, smiling students nod to conform they have fully understood something that we later find they have not understood in anything like the way intended. Perhaps we could send that group off to become post-modernist social scientists, but that would be a loss for the natural sciences!

So, here comes the crux of my talk, which is, in effect, a question.

Should science communication be about promoting subjective or objective understanding?

Now, I argue that in teaching, and in scientific papers, both are really important. We want our students to be able to get right answers in assessment, and feel confident about their knowledge. The same surely applies with regard to authors and their colleagues with when talking about research reports and reviews within a scientific community.

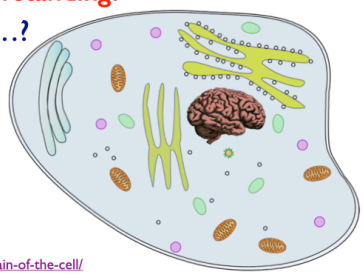
But what about the brief news report item, the science documentary, the popular science book, the outreach talk intended to engage a general audience, and the like. Should these be intended to bring about subjective and objective understanding - or is subjective understanding sometimes enough? If a journalist has a 30 second spot to explain some breakthrough in cancer research or new discovery in deep space, is it enough to give the audience members a feeling that they have got the gist of the scientific achievement? If someone reads a popular science book about the immune system or black holes or volcanoes, should they only expect to feel they have learnt something or have a reasonable expectation of actually acquiring some creditable knowledge?

Examples of figurative language…

Since retirement has given me more time for reading for interest, I have come to be rather obsessed with such questions because of the large number of metaphors and analogies and the like I have noticed. Some seem ingenious and apt. But, some of these I have felt would only work for someone who already understood the scientific point being made, and some I felt did not really explain very much, but just offered a familiar image or comparison which might act at best as a kind of placeholder for genuine understanding. For example, a phrase like 'the nucleus is the brain of the cell' could be a very productive one if it was the starting point for an enquiry into in what sense or senses the nucleus of a cell might be said to be like - or unlike - a person's brain in their body. But by itself, it is just a motto, a slogan, that may give the impression that I understand what the cell nucleus does - it *is* the cell's brain.

examples of figurative language…

- that only work for someone who already understood the scientific point being made?
- not really explain very much but just offered a familiar image or comparison which might act as a kind of placeholder for genuine understanding?
- starting point for an enquiry…?
- just a motto; a slogan?



https://science-education-research.com/the-nucleus-is-the-brain-of-the-cell/

2

Some comparisons that are used to introduce people to technical ideas are more obvious than others!

If figurative comparisons are easy to interpet, we should *readily* be able to pair up target concepts and comparisons …

The challenge is to see if you can identify *which* ***comparison*** was used in discussing *which* ***science*** *concept*:

target science concept	*comparison used*
antiaromaticity	blockage of emergency fast lane
atomic energy levels	dark alter-ego
blood-brain barrier	fingerprints
black hole	four-seater car or four-man boat
covalent and ionic bonds	gloves or socks
Ebola	Great Wall of China
haemoglobin	kinds of human relationships
molecules	merry-go-rounds
proton pumps	missing Mars bar
water voles	waste disposal unit

https://science-education-research.com/science-communication-challenge-1/

3

I have posted this challenge where I have separately listed 10 scientific concepts and the comparisons used to help explain them. Of course, in the original sources there was useful context, but when isolated like this I am not sure it is obvious which scientific idea matches which comparison. Indeed, I am not sure I can now explain some of these links.

[2] https://science-education-research.com/the-nucleus-is-the-brain-of-the-cell/

[3] https://science-education-research.com/science-communication-challenge-1/

The constructivist perspective

I am now almost ready to ask you to look at some examples.

First, however, I am just going to reiterate some basic ideas about learning and understanding that I suspect are widely familiar in our community. However, teachers should be wary of making such assumptions, so just in case…

Human learning is incremental, interpretive, and iterative. It is incremental because a person's working memory has a very limited capacity to handle new information. So complex material needs to be deconstructed into modest learning quanta which are presented at a pace human cognition can cope with.

Learning is interpretive because in order to make sense of new information we rely on the resources we already have available. This is why comparisons with what is already familiar are so useful - they help make the unfamiliar familiar . Because learning is incremental and interpretive it tends to be iterative - we tend to more readily accept things that fit with our existing way of thinking and build up new understandings accordingly.

But back here, in the real world, teaching often goes wrong because teaching is not made sense of in the way the teacher hoped. Teachers can at least monitor how they are understood using formative assessment techniques, and so adjust their presentations. That facility is not available to the science communicator writing a text or being interviewed on the radio or giving a one-off public talk.

So, to some examples…

Simile

Descriptive simile

Mary Somerville (in 1869) describes anatomic features for the general reader:

> "…wart-like…hair-like…necklace-like…like long shaggy grey hair…like Japanese or Chinese characters…looking like little flat headed pins…like little necklaces…like a carriage wheel without the rim…shaped like flasks with long necks…urn-like vessels…a kind of collar…flask-shaped…like a sponge…wire-like…like a crosier…vase-like…"

I want to start by considering similes, where the science communicator sets out to make the unfamiliar familiar by pointing that in some sense the unfamiliar target is a bit like something already familiar. Some of the most basic and unproblematic examples I have found are where naturalists are describing some species, so perhaps a part of a plant, by suggesting it is shaped like some familiar everyday item.

"The animal when lively is constantly clasping these bristle-like teeth together, over its mouth...

The two pair of lateral fins and that on the tail lie in the same horizontal plane...they appear to consist of excessively fine transparent rays, touching each other, like the barbs of a feather..."

Charles Darwin

"... I caught a very small bee...and placed it in the labellum [of a Cypripedium flower] through the upper large opening. The bee vainly endeavoured to crawl out again the same way, but always fell backwards, owing to the margins being inflected. The labellum thus acts like one of those conical traps with the edges turned inwards, which are sold to catch beetles and cockroaches in the London kitchens."

Charles Darwin

Of course, even here, as with this last comparison, we are reliant on the audience having the right *interpretive resources*, and some comparisons may go out of date and may be less clear to a contemporary reader.

"In an escarpment of compact greenish sandstone I found a small wood of petrified trees...they consist of snow-white columns (like Lot's wife) of coarsely crystallised carbonate of lime. The largest shaft is seven feet."

Charles Darwin

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?

Lot's wife

"In an escarpment of compact greenish sandstone I found a small wood of petrified trees...they consist of snow-white columns (like Lot's wife) of coarsely crystalized carbonate of lime. The largest shaft is seven feet."

what 'interpretive resources' would be needed to understand the scientific point?

However, I would also point out that neither Darwin or Henslow or 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. 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.

Similes

I am using literary terms like simile and metaphor. There is a distinction there that I think is important. A simile is marked as a comparison. So it may be to suggest X is *like* Y, or X is Y-*like* or X does something in the way Y does. Or it may report that X is *said to be* a Y, but the Y is put in 'scare quotes', or there is a qualification such as '*so to speak*', '*if you like*', or '*in a sense*' to mark the simile.

Here are some examples which you may, or may not, interpret as the science communicator intended. I am not going to comment much on these examples, as I would like to give you all a chance to reflect on them.

focal questions

what might a non-specialist understand from the text?

(what interpretive resources must the reader/listener bring to bear?)

What might a non-specialist understand from the text:

> "... rare elements and heavy atoms, as trace elements play an important role for life; with their very special qualities they are, in a manner of speaking, the 'spice' in the soup of life."
>
> Brueuer, R. (1990). The Anthropic Principle. Man as the focal point of nature

What might a non-specialist understand from the text:

> "It must however be noticed here that the process of shrinking and cooling of the old stars which have used up all their vital hydrogen fuel does not always proceed in a quiet and orderly way, and that, walking their 'last mile', these dying stars are often subject to titanic convulsions as if revolting against their fate."
>
> George Gamow

What might a non-specialist understand from the text:

> "As the nuclei became heavier, the [relativistic] effects became more pronounced. By the time the model reached oganesson, the supposed electron shells are more like electron soup."
>
> Chapman, K. (2019). Superheavy. Making and breaking the periodic table.

Here is a selection of other examples, or at least my 'headline' versions of them [4]:

- bacterium is like a tiny attack submarine
- Bessemer process was a sort of meteor
- Betelgeuse is like an imbalanced washing machine
- biological messenger molecular is like a legal summons
- correspondence principle was used as a sort of spare wheel
- discovery learning methods spread like a virus
- D.N.A. strands attract like magnets
- during boiling molecules fly apart like a flock of frightened birds
- elementary particles can be organised into kinship groups
- Empress Cixi learnt the circuit board of the Qing court
- endocrine system is like a Ferrari
- eye lens is a kind of secretary
- gas molecules are like frantic bumper cars
- genome is like a graveyard filled with ghosts
- genome resembles a musical score
- human brain resembles the cabbage
- hospital processed lithium like a small outback mining town
- innate immune system is like antiviral software
- interferons languished in a sort of scientific Siberia
- Kupffer cells hang around like spiders on the walls
- liquid molecules crawl like worms
- long-term memory is like a corroded filing cabinet
- many bacteria have a sort of gearing system

[4] see https://science-education-research.com/public-science/examples-of-science-similes/ for further details of the original quotes.

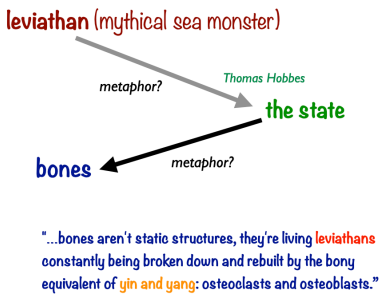
- monoclonal antibodies are like demented postal workers
- neutron star is like a stellar wreck
- Newton's theory of light was like a punch-drunk boxer
- nuts contain something like thousands of shoeboxes
- patterns on brain scans resemble Captain Scarlet's Mysterons
- pentamer is a sort of antibody throwing-star
- pools of dissolved lithium salts are like a disturbed artist's palette
- selection theory is like a Tibetan prayer-wheel
- shortening of the telomere is like the fraying of a shoelace
- skin acts like a handkerchief
- skin cells are like tiny chameleons
- spider webs are found in fly interchanges
- stable superheavy elements seemed like ghost
- sulphur nanoparticles are bound in the cathode in a sort of spiderweb network
- trust changes form like energy
- vaccine acts like a wanted poster
- venous blood behaves like a fluttering frightened hen

Metaphor

I use the label metaphor when we are told an X is a Y without any indication this is meant figuratively, not literally. This potentially adds an extra burden for the audience, as they have to first spot that a comparison is being made, before they can interpret the meaning. Here are some examples which you may or may not interpret as the science communicator intended.

What might a non-specialist understand from the text?

> "...bones aren't static structures, they're living leviathans constantly being broken down and rebuilt by the bony equivalent of yin and yang: osteoclasts and osteoblasts."
>
> Carver, C. (2017). Immune. How your body defends and protects you.



[5]

[5] I can only make sense of this by assuming the reference is not to the mythical sea monsters themselves, but rather Thomas Hobbes's metaphorical use of the term, making this a metaphor to a metaphor.

What might a non-specialist understand from the text?

> "The primary regulator of fat cell formation (adipogenesis) is considered to be peroxisome proliferator activated receptor gamma (PPAR-[γ])....This receptor has a large promiscuous pocket that is vulnerable to hacking by multiple obesogenic ligands."
>
> Chemistry World

What might a non-specialist understand from the text?

> "...you get the cortex which is your higher centre, then you've got some of these subterranean regions like the limbic system which does emotion and memory, and the brain stem..."
>
> BBC radio/podcast series 'Dementia: Unexpected Stories of the Mind'

What might a non-specialist understand from the text?

> "All of these species have a remarkable ability to move about by using a diverse array of swimming, digging, and hopping behaviours. They accomplish this with a virtual Swiss army knife of legs: some are large, others small, some face forward, still others face backward."
>
> Shubin, N. (2020). Some Assembly Required. Decoding four billion years of life, from ancient fossils to DNA

What might a non-specialist understand from the text?

> "genome back in 2003...Roughly about two hundred million bases long that were missing. It was roughly eight percent of the genome was missing...we think about tandem repeats or pieces of sequences that are found in a head-to-tail orientation in the genome, these are corners of our genome where this is just on steroids, where we see a tremendous amount of tandem repeats sometimes extending for ten million bases. They are just hard to sequence..."
>
> Dr Karen Miga interviewed on an episode of 'Science in Action'.

What might a non-specialist understand from the text?

> "Huygens's discoveries do surely have an intoxicating appeal. As [an] American science writer has suggested, haloed Saturn is, for many amateurs, the 'gateway drug' to their astronomical habit."
>
> Hugh Aldersley-Williams (2020) Dutch Light. Christiaan Huygens and the making of science in Europe. Picador.

Extended metaphor

Take a theme and run with it (well, figuratively speaking, of course)

Sometimes one comes across extended metaphors, which start to approach formal analogies. Here are some examples which you may or may not interpret as the science communicator intended.

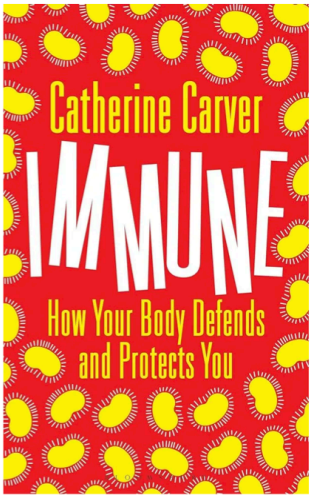
What might a non-specialist understand from the text?

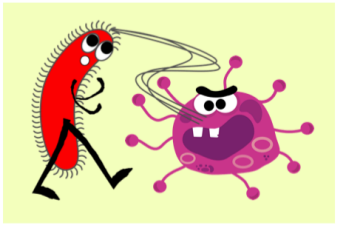
> "Astronomy is thus a four-legged animal standing on sound and false ideas at the front and sound and false observations at the rear. Amazingly, the beast can limp forward, sometimes even gallop, from one discovery to the next. And lurching on its way to valuable information about the nature and history of the universe it has in passing exposed the character of those ephemera, the tails of comets."
>
> Calder, N. (1980). The Comet is Coming! The feverish legacy of Mr Halley. British Broadcasting Corporation.

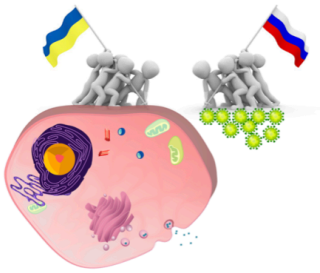
From the same source:

> "If the 'new' comets seem to be coming from starting points half a light-year out, that is where they have been in residence since the birth of the Solar System. Such is the leading idea about the origin of comets, that is to say the theory not disfavoured in Cometsville. All the other other categories of comets are, in this scheme, pilgrims from the coolest provinces of the Solar System who lost their return tickets and are trapped in shorter orbits around the Sun, waiting either to perish in the heat or to be evicted into interstellar space and exiled from the Sun for ever. But the theory requires the existence of a large population of unseen comets to sustain the pilgrimage, and thus it endorses the opinion of Johann Kepler that 'there are as many comets in the sky as fishes in the sea'.
>
> The devotion of comets to the gravitational faith that unites the Solar System appears in this: their first journeys from the outer darkness to the altar of the Sun take a very long time indeed, for the sake of a fleeting visit. When the priests of this faith, the celestial mechanicians on the Earth, interrogate 'new' comets now arriving in the Space Age they admit to travelling for several million years."

This is an example of the metaphorical density of figurative language in some popular science writing. And it is not a complete outlier.







https://science-education-research.com/disease-and-immunity-a-biological-myth/

This is perhaps an extreme example, as this book [6] sets out to present disease and immunity in terms of an extended military analogy. Of course, this is by no means unique to this account, but I doubt many other uses of the analogy have involved such an *intensive bombardment* of a reader. In many ways this is a useful analogy, but whereas a good teacher would examine both its strengths and limitations, knowing that areas of difference are also useful teaching points, the popular science author may not.

> "neutrophil is a key soldier...the human body is like an exceedingly well-fortified castle, defended by billions of soldiers...the incredible arsenal that lives within us...the hidden army...our adaptive assassins, our T and B cells...The innate system is the first line of defence...an exquisite barrier that keeps unwanted invaders out...your airways are exceedingly well booby-trapped passages lined with goblet cells, which secrete a fine later of mucus to trap dirt and bacteria...Initially it was seen as a simple soldier with a basic skills set...Now we know it is a crafty assassin with a murderous array of killing techniques...ninja skill of neutrophils...ninja neutrophils...macrophages are stationed at strategic sites...what an important outpost the liver is for the immune system...NK cells [have] killer ways...trigger-happy NK cells...Ever neat assassins, NK cells...vicious immune cells" compared to "a pack of really hungry Rottweilers...pro-inflammatory little fire-starters... neutrophils, macrophages and other immune system soldiers...T cells...activate their invader-destroying skills...a weapon with a name worthy of a Bond villain's invention: the Membrane Attack Complex...miniature mercenaries...a system whose raise d'etre is to destroy foreign invaders...everything we do exposes us to millions of potential invaders...all invaders need an entry point...these tiny sneaks...the dark-arts of pus-producing bacteria...this particular invader...foreign invaders...an aggressive border patrolæ...Tregs are the prefects of the immune system...the parasite larva has more in common with a time bomb...T cells...are the grand high inquisitors of the immune system, spotting and destroying infected cells and even cancer...these assassins... imagining you have to make a Mr Potato Head army, and you know that the more variety in your vegetable warriors the better...this process is about ...making a mutant army...they form a fighting force that rivals Marvel Comic's Fantasic Four...each antibody molecule released as a single soldier...The pancreas ... acts as the commander-in-chief when its comes to controlling blood

[6] https://science-education-research.com/disease-and-immunity-a-biological-myth/

sugar levels...our tiny but deadly defenders...cells in the spleen with a specialised killer-skill...wears a mask that conceals its killer features from its would-be assassins...the microbiological mass murderers...the serial killers...PA is the muscled henchman...the murderous cast of immune cells and messengers...this awe-inspiring army...a microscopic army, capable of seeking out and destroying bacteria...the terminators are targeted killers...weaponised E. coli...a kamikaze blaze of microbe-massacring glory...an eternal war between our bodies and the legions of bacteria, viruses, fungi and parasites that surround us...these invaders' attempts are thwarted...battles...all my innate defences would essentially hold the fort and in many instances this first line would be enough to wipe out the invader before the adaptive system gets a chance to craft bespoke weaponry...the tears we shed [are] a form of chemical warfare...allowing the neutrophils to migrate through the blood vessel and into the battlefield of the tissue beyond...the cell contracts itself tightly before exploding...their friendly fire contributed to the death of the victim...spewing microbe-dissolving chemicals into the surround tissue. This allows the neutrophil to damage many microbes at once, a bit like fishing by throwing dynamite into the water...NK cells target the microbes that have made it inside our cells...NK cells attack...the initial hole-poking assault...all part of the NK cell's plan to kill the cell...they trip the cell's self-destruct switch...expose a cell to a severe, but not quite lethal threat...transform the cell into a hardened survivor...ability to go on the rampage...call up ... immune system soldiers to mount a response...leukaemia ... has decimated a type of white blood cells called T cells...it behaves like a Trojan horse...telling our soldier cells to kick back and take some R & R...the smoke signals of infection...like a showing of tiny hand grenades on the surrounding cells....the donor cells would be vastly outnumbered and it would be like a band of rebels taking on a vast army on its home turf...the recipient's own immune system is in a weakened state and unable to fight back...the antibodies ...are therefore able to give a hostile welcome to alpha-gal-wearing malaria parasites....our gut bacteria effectively provide a training ground for the immune system – a boot camp led by billions of bacteria which teaches us to develop an arsenal of antibodies to tackle common foreign invader fingerprints...fighting on certain fronts...edgy alliance...shore up the intestinal defences by reinforcing the tight junctions which link the gut cells together...our gut's security fence...a self-cell that should be defended, not attacked... this mouse-shaped Trojan horse...the scanning eyes of the immune system...a form of border control, policing...the bacteria-bashing brilliance...the IgA effectively blocks and disables the invaders' docking stations...B cells and their multi-class antibody armoury have the ability to launch a tailored assassination campaign against almost anything...the exquisitely tailored assassination of bacteria, viruses and anything else that dares enter the body...One of the seminal victories in our war on bugs...Some bacteria have a sugar-based cloaking device...tripped by the pollen attaching to the IgE-primed mast cells and, like pulling a pin on a grenade, causing them to unleash their allergy-inducing chemicals...The almost instant assault of the immediate phase reaction occurs within minutes as the dirty bomb-like explosion of the mast cell fill the local area with a variety of rapidly acting chemicals...the battle against infectious diseases....teaching the patrolling forces of the immune system to stand down if the cell they're interrogating is a healthy cell that belong to the body. It's a bit like a border patrol force wandering through the body and checking passports...like a training camp for the newly created border guards...ordering those that react incorrectly to self-destruct...These bacteria have a sugar-based polysaccharide outer shell, which acts like a cloaking device...the viruses have a Swiss army knife selection of killer techniques...This approach slaughters these foot soldiers of our immune system...they have picked up a time bomb...antibodies that act like heat-seeking missiles...Kadcyla ...has a double-pronged

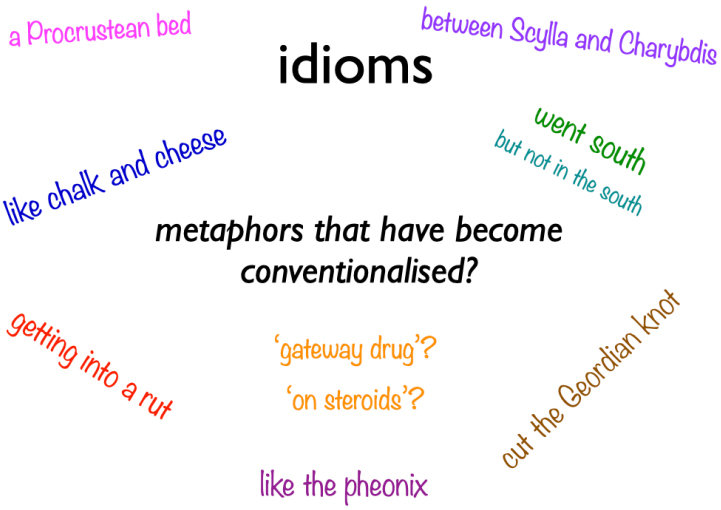
> attack...we are setting up easy antibiotic assault courses all over the place...His suicidal minions were engineered to seek out a pneumonia-causing bacterium by the name of Pseudomonas aeruginosa and explode in its presence releasing a toxic cloud of a Pseudomonas-slaughtering chemical called pyocin...it could secrete its killer payload...stimulate the little terminators to produce and release their chemical warfare."

Simile-to-metaphor transitions

One common feature illustrated in this next example is how a comparison introduced initially as a simile ["sort of lights a fire"] is then treated as a metaphor ["that fire"] - presumably for economy of expression.

> "But even after someone is infected, the host actually mounts, for all these [respiratory] viruses, a really dramatic immune and inflammatory response. So it sort of lights a fire. And even when the virus stops replicating, you know that fire continues to burn, and in a lot of cases that's what lands people in the hospital. And so you want to prevent the virus from igniting that fire, that is what really ends up causing a huge amount of damage to the patient. ...the greatest benefit [of the antiviral drug being tested] is in the outpatient setting before that fire gets ignited."
>
> Dr Daria Hazud ,interviewed on an episode of 'Science in Action'.

Idioms



Idioms seem to me to be metaphors that become conventionalised. Presumably at some point someone who first used an idiom meant it as a metaphor, and expected its meaning to be clear to an audience Over time, the phrase has come to stand for a whole class of situations with something in common. Now the key distinction between a new metaphor and an idiom is that a naive person has at least a decent chance of making sense of most metaphors as the comparisons have been chosen to be meaningful to the audience.

However, the particular metaphorical meaning of idioms have to be familiar already to make sense, and I assume may be especially challenging to second language learners.

Consider this example:

> "if you punch an earth-bound asteroid too hard, it will fragment into several smaller but still dangerously sized pieces, effectively **turning a cannonball into a shotgun spray**. For bigger asteroids or for smaller earth-bound asteroids discovered with little warning time something, with more oomph [sic] may be required, a nuclear weapon. Park a nuke-armed spacecraft next to the asteroid, detonate, and one side of it [asteroid] will become severely irradiated. That side will shatter and jettison debris into space, pushing the asteroid away from earth **as if it were a rocket**. If the asteroid was discovered too late to deflect it away from the earth, we may try to completely vaporise it, with ever more powerful nuclear detonation. A **Hail Mary approach**, that risks **turning the cannonball into a now radioactive shotgun spray**."
>
> Dr. Robin George Andrews talking on BBC Inside Science.

Now there is clear simile there about the rocket, and I think the extended metaphor about about the cannonball and shotgun would be clear to most people. I think most people could work these comparisons out. But what about "a Hail Mary approach". Hail Mary is a traditional Catholic Prayer. [7] What has that got to do with asteroids?

Of course 'Hail Mary approach' is nothing to do with offering a prayer, but is said to mean a 'last ditch' effort.[8] But then isn't 'last *ditch*' also an idiom. Someone unfamiliar with English idioms might wonder what ditches have to do with anything. So, that's as clear as *ditch* water then.[9]

[7] "Hail Mary, full of grace. The Lord is with thee. Blessed art thou amongst women, and blessed is the fruit of thy womb, Jesus. Holy Mary, Mother of God, pray for us sinners, now and at the hour of our death, Amen."

[8] Presumably, the origin is from the idea that when all other options for action intended to bring about some outcome have been tried and failed, prayer is the only option left.

[9] There seem to be two alternative idiom variants here - 'as clear as ditchwater' and 'as clear as dishwater'.

What might a non-specialist understand from the text:

> "I think, deep down, the bit I love is that sort of Babel fish job, so being a translator in between the worlds of policy and the world of science. By getting them to aticulate their question very, very clearly, I can help them find the bit of science that is actually going to help them do their job better."
>
> Professor Dame Angela McLean (Dept. of Biology & All Souls College, University of Oxford), Chief Scientific Adviser to the UK government, was being interviewed on an episode of BBC Inside Science.

What might a non-specialist understand from the text?

> "'Hydrogen solubility in metal as a function of temperature and pressure is one of the new holy grails, I would say, of planetary research,' says Young [Edward Young at the University of California in Los Angeles]."
>
> Chemistry World

And science communication is *populated*, so to speak, by a great variety of metaphors, such as: [10]

- all reference-molluscs are equally valid
- Betelgeuse is bloated
- bioorthogonal chemistry is a cousin of click chemistry
- carbohydrate molecules are chemical springs
- carbon skeleton of an organic molecule clothes itself
- chemical elements are formed in the murder of neutron stars
- electrons dance around a cyclic transition state during electrocyclisation
- embryology is at an embryonic stage
- event horizon is a one-way door
- gamma-ray burst is due to feeding a black hole at a high rate
- gametes are the marrying cells
- lithium ions nestle in a happy house built of graphite
- forming the planets was in heavy traffic
- fossils are wrecks of nature
- grammarian systematisation is full of enantiomorphism
- human cells are surrounded by their close friends and partners
- iron fluoride islands act as lithium nucleation sites on a lithium fluoride surface
- islands are populated by flotsam and jetsam
- lasers knocked atoms up
- learning to read X-rays is picked up by osmosis
- lipids have split personalities

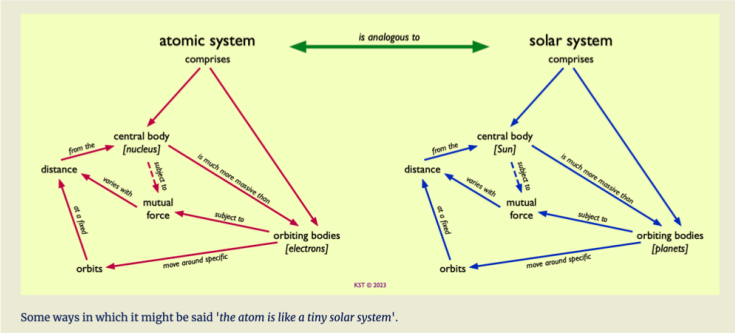
[10] Again these are 'headline' versions of longer quotes. See https://science-education-research.com/public-science/examples-of-science-metaphors/

- lithium was born at the start of the universe
- mathematician plays the role of a litmus test for a definition
- meteors give birth to craters
- microbiome is part of the immune engine room
- most galaxies harbour black holes in their hearts
- moths perform as marriage-priests
- moving electron digs a hole through the conductor
- mutated proteins can be rogue
- nervous system is a puppet-master
- nineteenth century anthropologists pieced together elaborate jigsaw puzzles
- nuclear power was beset by a cultural hysteresis
- physical anthropology was smash-and-grab style research
- Ptolemy's starry sphere was a cosmic jewel box
- protons are attracted by an electronic fur coat
- raw data should be carefully cooked
- reaction stopped by base-eating cannibals
- red blood cells have a best before date
- ribosomes are molecular workbenches
- Rorschach test is a fluoroscope into the psyche
- Saturn may have devoured his children
- skeleton is a framework of the most curious carpentry
- second law of thermodynamics is a terroristic nimbus cloud
- some antiaromatic molecules have been tamed
- supernova is the death-agony of a star
- syphilis is a daughter of leprosy
- T cells sniff other cells
- Thiomargarita magnifica is Godzilla of the microbial world
- Thomson dissected the delicate body of the atom
- volcano should be considered as a spiracle

Analogies

I consider an analogy to be a comparison between two conceptual structures where an explicit mapping is offered. Here are some examples of what I mean by this. I am not going to talk about analogy in any depth today as a well-framed analogy offers a clear mapping between the positive features that are analogous across the two systems; so, although analogies may be more or less useful to an audience, and still require the analogue to already be familiar, the reader or listener is not left to work out the relevance of the comparison for herself.

the atom is like a tiny solar system



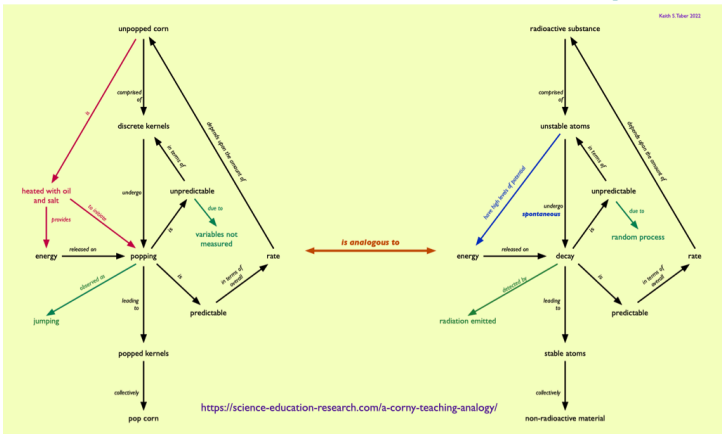
Some ways in which it might be said '*the atom is like a tiny solar system*'.

I would just take the opportunity to point that when used in teaching, it is important to highlight the negative as well as the positive features of analogies (just as it is important to introduce new concepts through non-examples as well as examples). We may think it is obvious that all electrons are identical and this need not be pointed out, but if the old atom as a tiny solar system analogy is met, why should a learner realise that unless it is pointed out? If that seems an extreme example…

> "When Rutherford (following Nagoka) conceived of the atom as a miniature solar system – electrons circling the nucleus as planets circle the sun – some philosophers suggested that electrons might really be planets with mountains, oceans and even living creatures."
>
> Norwood Russell Hanson

I do not expect you to take in the details of this following example, but just wanted to show that structural analogies between conceptual systems can get quite complex:

a teaching analogy - using popping corn to teach radioactive decay



[11]

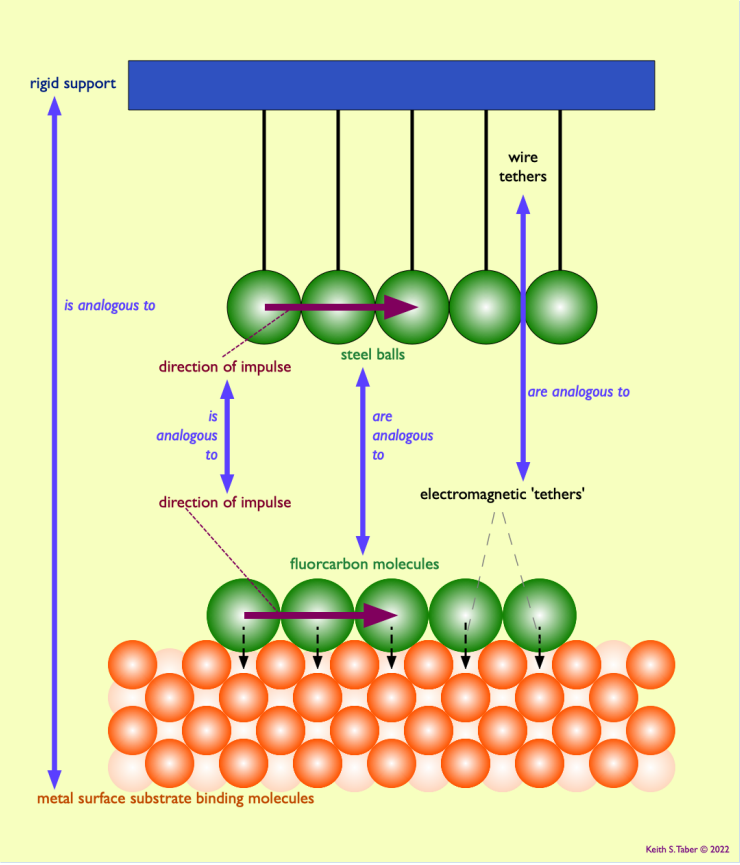
[11] https://science-education-research.com/a-corny-teaching-analogy/

What might a non-specialist understand from the text?

> "Molecular Newton's cradle challenges theory of transition states."
>
> Chemistry World

This was a headline in a science magazine. But the comparison was actually suggested in the primary scientific literature:

> "...energised F can move to- and-fro. This occurs in six successive linear excursions, under the influence of electron-induced molecular dissociation at alternate ends of the line.... The result is a rocking motion of atomic F which mirrors, at the molecular scale, the classic to-and-fro rocking of a macroscopic Newton's cradle."
>
> Chemical Communications



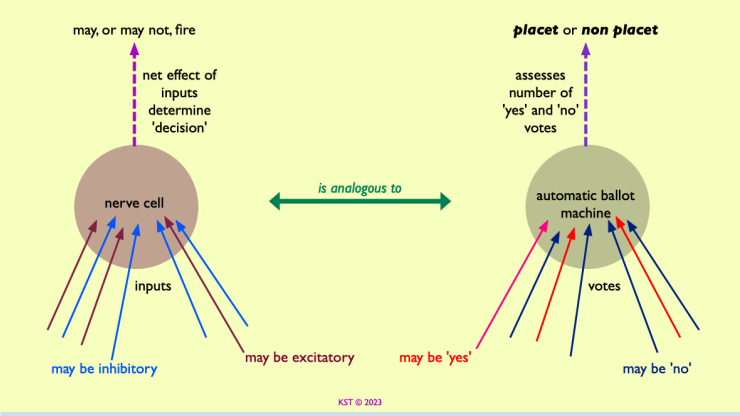
12

12 From https://science-education-research.com/a-molecular-newtons-cradle/

What might a non-specialist understand from the text?

> "So any single nerve cell acts like an [sic] tiny automatic ballot machine, assessing the number of 'yes' and 'no' votes entering it at any one time and either firing or not firing depending on which type of vote predominates at any one time. ...Nerve cells receive electrochemical signals from other cells, and each signal represents a 'yes' or a 'no' vote in an election to determine whether the cell should fire."
>
> Scott, A. (1988). Vital Principles. The molecular mechanisms of life.

I rather likes this analogy, represented schematically here[13]:



What might a non-specialist understand from the text:

> "Our sensory organs of the eye, ear, nose, palate, and skin are built according to the principle of a Swedish box of matches, in which the matches only respond to certain effects of the outside world."
>
> Jakob von Uexküll

What might a non-specialist understand from the text:

> "For Wassermann 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'. Nor was this all. Their 'voyage' was not straight sailing in a planned direction but an Odyssey with continual change of direction. What they achieved was

[13] https://science-education-research.com/making-molecular-mechanisms-familiar/

> not even their goal. They wanted evidence for an antigen or an amboceptor. Instead, they fulfilled the ancient wish of the collective: the demonstration of syphilitic blood."
>
> Ludwig Fleck

Perhaps everyone should know the story of the accidental discovery of the Americas: a discovery that came as no surprise to the people already living there of course. But I wonder about the additional cognitive load for a reader who lacked this point of reference.

What might a non-specialist understand from the text:

> "As we've seen, the immune system is like a very complex game of Mouse Trap, except all the different interconnected pieces work together to catch invading micro-organisms instead of cheese-thieving mice."
>
> Catherine Carver 'Immune. How your body defends and protects you'

What might a non-specialist understand from the text:

> "John Maynard Smith quoted another biologist who described the inheritance of acquired characteristics as being 'as if a man sent a telegram in English to China and it arrived of its own accord translated into Chinese'."
>
> Catherine Carver 'Immune. How your body defends and protects you'

Perhaps today we would no longer be surprised if our overseas communications were translated en route?

What might a non-specialist understand from the text:

> "I use the analogy that bacteria behave a bit like teenagers. They're constantly messaging each other and signalling when there is a high concentration of bacteria present in the same location by throwing a party when the parents are out of town."
>
> Dr Susan Woods speaking on 'Ockham's Razor'

Again, there are *many* more examples out there [14]:

- antigen to antibody is not like paint to wall
- as with the building of an Egyptian pyramid the raising up of a continent consists of many events happening in succession

[14] Again, these are 'headline' summaries - see https://science-education-research.com/public-science/examples-of-science-analogies/

- beetle's mate can change significance like a stone on the path
- benzene has Jekyll and Hyde behaviour
- bits of genome are like a coin in the bottom of your pocket
- black hole sucks in space like a drain hole sucks in water
- bodies of variable stars pulsate as regularly as the heart beats
- Brownian motion is like ping-pong balls bumping into a beach ball
- channels from various volcanic eruptions are like the arteries of the heart
- cicadas are the earth's dandruff
- compound formation is like a marriage
- conservation of mass in chemical reactions is like not distinguishing Eskimos
- diatomic molecule is a discus thrower that can spin only at certain speeds
- DNA is like an encyclopedia but metabolites are like a Twitter feed
- Egyptian embalming techniques were like preserving pears in sugar
- Enceladus is like a squeezed squash ball
- extant species are like the finite wavelength of light
- final causes are like virgins consecrated to God
- galaxies are like flocks of gas
- human development is like a lightbulb giving rise to a massive office block
- hunt for mutation is like searching 65 freight cars for one bad orange
- imaging exoplanet is like photographing a firefly that is next to a lighthouse
- investigating objects in space is like measuring the timbers of a ship
- lead in radioactive rocks is like beer cans on Pacific islands
- light transmission is like a bird passing through branches
- lithium is the penicillin of mental health
- membrane ion channel is like a turnstile
- mixing of ocean water is like ploughing a field
- molecules can be like gloves or socks
- objects are smeared around a black hole event horizon like oil
- phthisical soldier is like a glandered horse
- planets were like the rear lamps on bicycles
- plague is like the rain
- rusting of iron is murder
- solar system is an autocratic state rather than a democracy
- star after mass ejection is like a washing machine out of balance
- syn addition is like a UFO returning a cow
- to cross a pn junction holes have to climb a hil
- unstable atom is like a miser

Anthropomorphism

A particular class of metaphors are those which present nonhuman entities as having the feelings, perceptions, motivations, reflections, intentions and actions of people. This issue of the scientific validity of

engaging figurative phrases was one I was already concerned about in my doctoral studies. I wrote a paper with my supervisor, Mike Watts, about the anthropomorphic language used by my students in talking about atoms and bonds and electrons and the like - as in these examples [15]:

anthropomorphism

"I think this atom would want to lose an electron and become an ion, but on its own, no, I think it's just happy on its own."

"two positive charges always 'repel each other' 'because they're the different charges and they don't like each other"

"fluorine's being greedy trying to grab two electrons"

"the first shell, it needs two electrons to become stable... it joins with another hydrogen, and it shares, the other hydrogen's electron, so it thinks that it's got two electrons"

I came to the conclusion such anthropomorphism could be a useful temporary crutch (if you excuse my metaphor) in coming to think about the unfamiliar micro-world so critical in making sense of chemistry - making that unfamiliar world seem familiar enough to not seem scary and too abstract, and so allowing the potential for the development of more canonical arguments and explanations. But, too often, these intended temporary pseudo-explanations become permanently adopted by learners as if the explanations they need to learn and apply.

What might a non-specialist understand from the text:

"if you see X-rays coming from a star, it's like a flag that the star is waving at you saying, 'look at me, look at me, I'm interesting'."

Prof. Paul Murdin (Institute of Astronomy, University of Cambridge) talking on the radio

What might a non-specialist understand from the text:

"atoms...look for others to bond with, in ways that will complete them....Sometimes there is a true meeting of minds, in the form of an electron being shared; others happen when one atom gives up an electron for the sake of another...Hence atoms are engaged in a sort of chemical speed date to find the right partner or partners to fill their quota..."

Pang, C. (2020). 'Explaining Humans. What science can teach us about life, love and relationships'

[15] Taber, K. S., & Watts, M. (1996). The secret life of the chemical bond: students' anthropomorphic and animistic references to bonding. *International Journal of Science Education*, 18(5), 557-568. https://doi.org/10.1080/0950069960180505

This is a from a fascinating account written by a neurodiverse biochemist who argues that she understands human relationship in terms of chemical interactions. My own reading of what is going on is rather different, but she is clearly in the privileged position to comment.

Perhaps some anthropomorphism is more difficult to take literally, and so more easily recognised as figurative?

> "Actually a four-dimensional manifold is amazingly ingenious in discovering new kinds of contortion, and its invention is not exhausted until it has been provided with six extra dimensions, making ten dimensions in all."
>
> A. S. Eddington - public Gifford lectures

When other examples of anthropomorphism may be more insidious? [16]

What might a non-specialist understand from the text:

> "you see a little drop of water, a tiny drop. And the atoms [sic[17]] attract each other, they like to be next to each other. They want as many partners as they can get. Now the guys that are at the surface have only partners on one side here, in the air on the other side, so they're trying to get in. And you can imagine...all trying to have as many partners as possible and the guys at the edge are very unhappy and nervous and they keep pounding in, trying to get in, and that makes it a tight ball instead of a flat, and **that's what, you know, surface tension**...everybody is trying to get into the water"

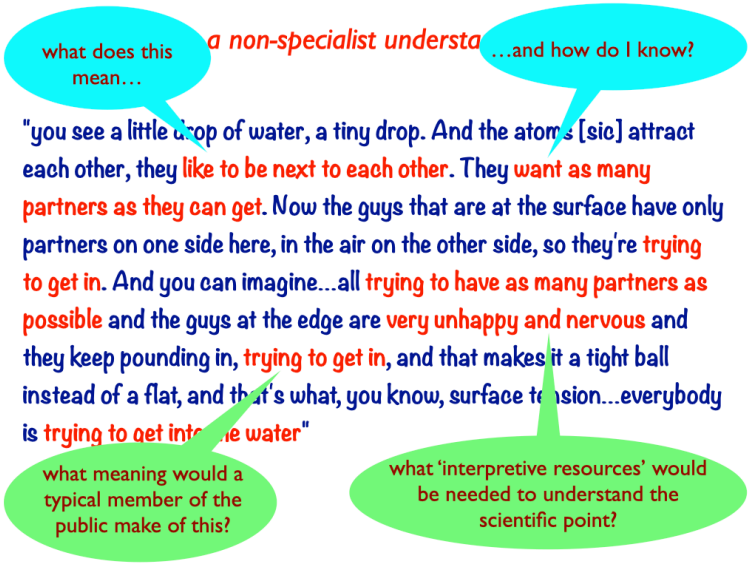
---

[16] From https://science-education-research.com/what-covid-really-likes/

[17] To a chemistry teacher this is an alternative conception that a school child would be corrected on, but for many purposes physicists do not distinguish atoms from molecules. Presumably, Feynman did understand the distinction.

Richard Feynman

This is from the great Richard Feynman. But I do not find this *explains* very much at all.



The big issue here is not that a person has to work hard to make sense of such passages, but rather that *they are easily made sense of* - as long as one accepts that inanimate objects such as molecules and electrons and so forth have feelings and perceptions, and thoughts and desires and intentions, and act deliberately. *It is the most natural thing in the world to understand clouds and stars and crystals and microbes through the way we experience the world* - the problem surely is that this is not the scientific account and the scientific account may sometimes be obscured rather than revealed through such usage.

Again, this type of thing is common in science communication. [18]

- antiaromatic molecules are anxious
- aromatic molecules are happy with themselves
- asteroids and comets attempted to deliver volatile substances to Earth
- atoms try to climb out of magnetic trap
- austenite does not want to change crystal structure
- bacterium will sneer at the statement that heat cannot go over into mechanical motion
- bees realised meat was available and decided to stop being vegetarian
- Betelgeuse shows petulant behaviour
- biosphere has learned to recycle phosphorus
- cells know what they need to do; they will do what they know how to do best
- chemicals work hard to reach the ozone layer
- cool air tries to push away the warm air
- cooled glass tries to contract

[18] Again, these are 'headline' summaries - see https://science-education-research.com/public-science/examples-of-anthropomorphism/

- curved violin string wants to go back to being straight
- Earth established itself as an important object in the solar system
- Earth is trying to cool down
- element is eagerly trying to complete its outer shell
- fireflies will murder and steal
- fish hope some of their eggs survive
- gravity of dark matter likes to bring everything together
- gravity tries to pull a white dwarf to be even denser
- HF loves the idea of donating a fluorine to SbF_5
- hill urges holes to cross pn junction
- jet tries to becomes a cylinder
- lightning is charge trying to ground itself
- meteors and meteorites are impetuous
- microbes think about where to live
- molecules in a gas have a high old time
- molecules of different conformation prefer different reaction pathways
- molecules pleaded allegiance to Newtonian mechanics
- monkey is concerned about lack of protein in diet
- moths thought switching to eating clothes would offer a better life
- natural killer cells know when they have found a stressed-out cell
- neurone tries to make contact with a neighbour
- noble gas atoms are completely self-satisfied
- our sun was lonely before the planets were formed
- photon knows how thick a window is
- proteins and amino acids and water desired a calm welcoming environment
- sea-urchins lead a contemplative life
- some genes just live to jump around
- tectonic plates attempt to move past or towards one another
- tumour cells try to evade the immune system
- virus thinks England and Scotland are the same country
- white dwarf steals from its companion star

What do you think?

My intention today is more to pose questions, rather than suggest answers. So, I want to finish with some points for discussion:

Normative questions:

- Should science communication be about promoting subjective or objective understanding? [19]

[19] I pose this as a genuine question. My instinct is that feeling one understands should not be enough, but perhaps others disagree?

- good enough to satisfy audience?
- sufficient to encourage public support for science?
- sufficient to encourage public support for science?
    - but what if curiosity has been satiated by subjective understanding?

Empirical questions: [20]

- If objective understanding is intended as an aim: how do members of the general public understand various examples of the use of figurative language in public discourse?
    - do they usually notice the indicators of simile ('like', 'as', 'so to speak', etc.?)
    - how often is metaphor appreciated as figurative, and needing interpretation?
    - when a simile is transposed into a metaphor after introduction, does the audience recall that it is a figure of speech?
    - is anthropomorphism recognised as a form of metaphor that needs to be interpreted?
        - …and does this depend upon *what* is being anthropomorphised:
          mammal, microbe, molecule, manifold…?
    - are idioms recognised for their intended meaning
        - especially by second language speakers?
    - do readers/listeners look for the points of 'negative analogy' as well as those that map from figure to target concept?
- If subjective understanding is sufficient: are members of the general public satisfied with figurative accounts as scientific explanations?
    - Do they 'feel' they understand various examples of figurative language?

Over to you…

View the presentation at
https://science-education-research.com/publications/miscellaneous/whats-the-point-of-explaining-science-in-the-public-domain/

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[20] I think there is a fascinating research project to be undertaken here.