The role of imagination and creativity in science and the importance of encouraging imagination and creativity in science education

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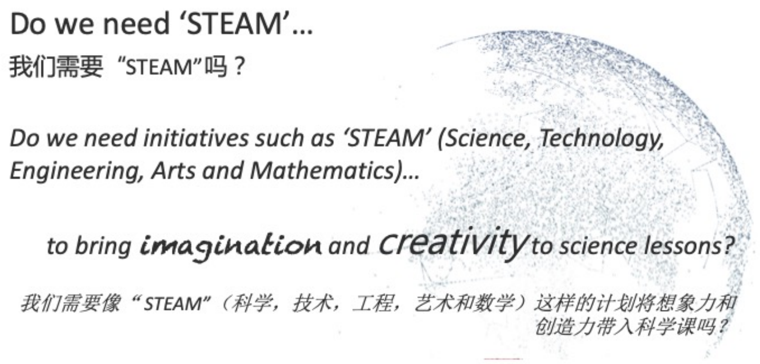
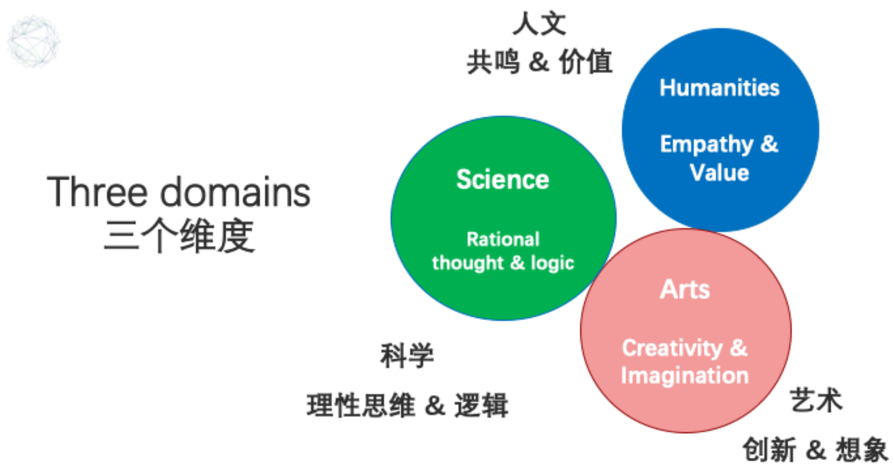
A video version of this talk may be found at:

https://science-education-research.com/publications/miscellaneous/the-role-of-imagination-and-creativity-in-science-and-science-education/



There has been a good deal of work exploring such ideas as 'STEAM' - looking to develop cross-curricular learning, which relates the already quite distinct areas of science; mathematics; and engineering and technology; with the arts. As one example, learners might be asked to write a poem based on some science topic they are studying.

In this talk I am going to take a somewhat different focus: rather than seeking to discuss how science can be hybridised with (what are considered) creative subjects, I want to consider how imagination and creativity can be engaged with from *within* science and the teaching of science. This is not to suggest that there is not value in cross-curricular approaches, as there most certainly can be much benefit to learners. However, as a scientist I worry that science is widely mis-characterised as one-dimensional, and I want to argue for a more nuanced understanding of the nature of science within science teaching.

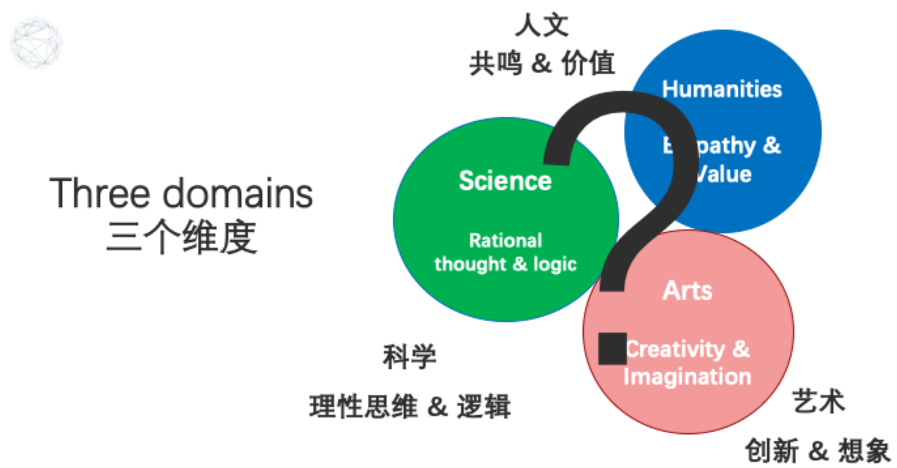


I am going to start with a caricature of the curriculum. This is at least a caricature of the subject-based curriculum in England where I have worked, and I think it applies much more widely. I am going to suggest we might see the curriculum as addressing three domains of human activities and concerns.

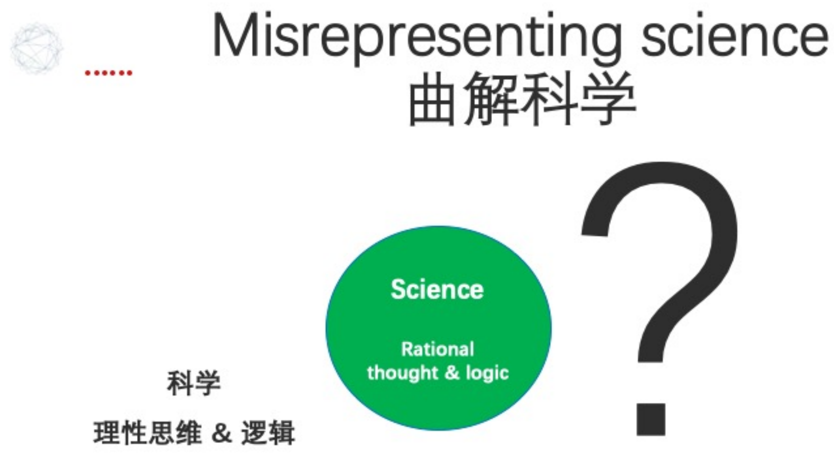
One of these domains concerns humanities subjects, such as history, philosophy, religious studies, and literature. These subject are concerned with questions of what it is to be human, and how we should behave, and with trying to understand those from other places, other times, other cultures - or just those we meet who inevitably are different in some ways from ourselves. How do they feel? How does someone feel when the person they love rejects them; or when they are subject to sexist or racist discrimination; or when told they have an incurable disease; or when their child has gone missing, or…? Clearly such matters are at the core of developing to responsible adulthood - but, perhaps not obviously anything to do with science.

Another domain is the creative arts: music, painting, decorative ceramics, dance, and so forth. These subjects show us ways that have developed in our cultures to allow us to express ourselves. Music is said to be the food of love, and also to have charms to soothe a savage breast (and in regular misquoting, to soothe a savage beast!) Music can make us joyful, or patriotic, or can bring us to tears. Great art can make us feel we are one with the cosmos - or that we are insignificant. Again, it is not obvious that science has much of a role here.

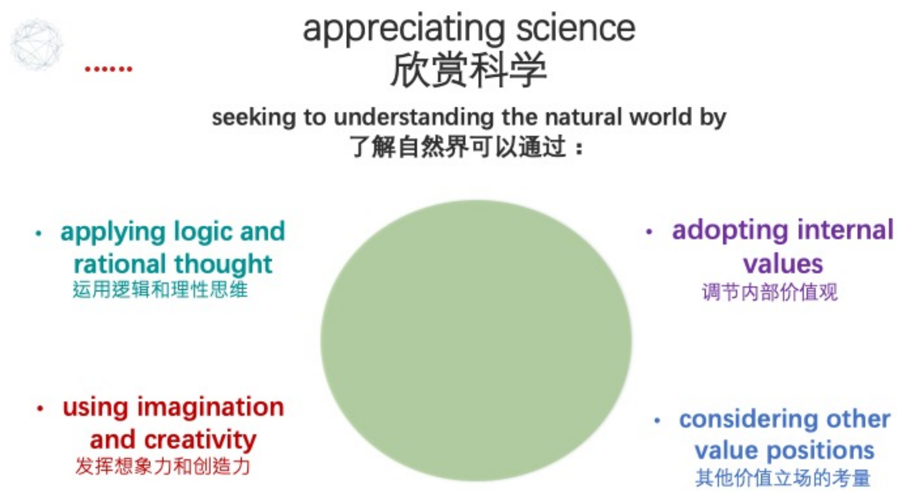
Science seems to occupy another domain - one that is based not on feeling, or judging right and wrong, but cold logic. The application of rational thought to better understand the world and to address practical problems.



I am certainly not going to deny that this is a major part of the essence of the natural sciences. But I do question this as a model of a kind of demarcation of responsibilities within the curriculum.



Such a model sells science short, misrepresents its full nature, and so can limit the potential of science teaching to offer a fully authentic science education.

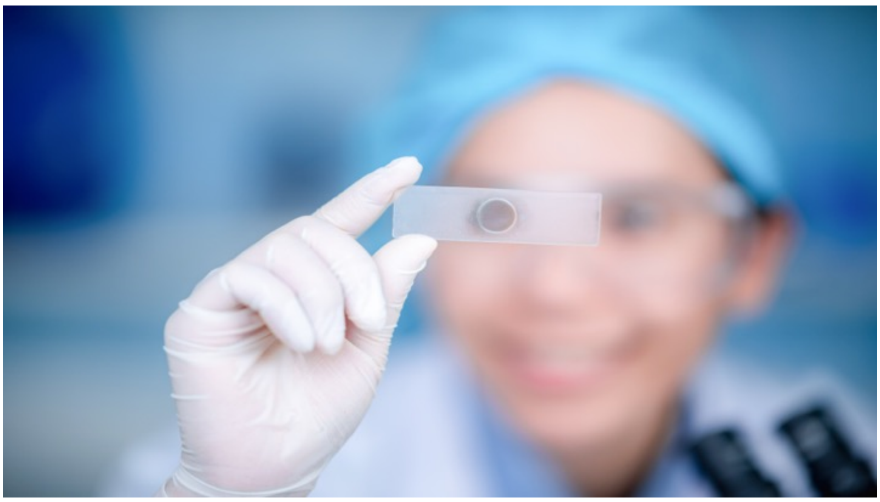


So, science and science education is indeed very much concerned with logic and rational thought, but it is also about values. Certain core values are inherent to science itself, and so any authentic science education must address the values of science. And, the application of science centrally involves issues of values, and often having to negotiate between different systems of values. It is possible to take a position that the scientist is concerned with the science, and decisions about application are matters for others - industry, the government, and so forth.

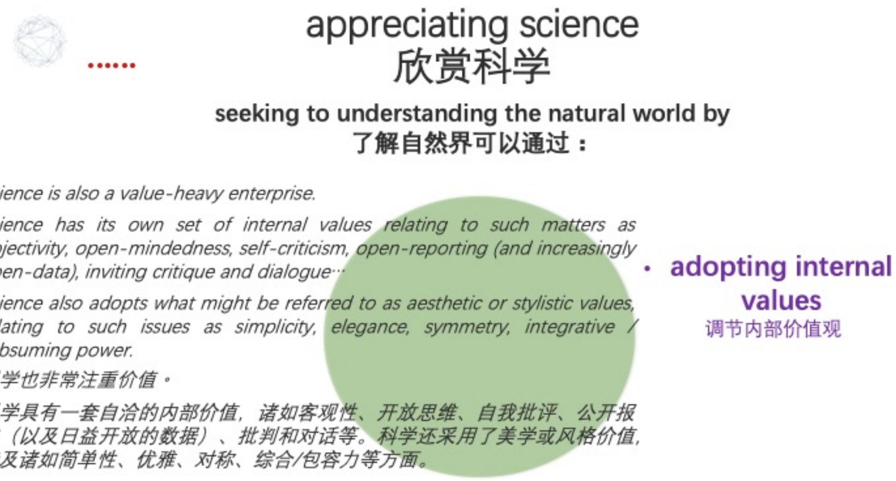
However, this would unreasonably excuse scientists from responsibility for their part in developments they know could be harmful, and ignores the humanitarian motives behind much science. It also ignores how science education is not just an education for future scientists, but for those who will make decisions about the application of science - and actually, at some level, that is all of us.

Finally, and central to my presentation today, science is not just a cold, rational process, but a process that is creative, and calls upon human imagination.

I am not going to say much about the importance of logical and rational thought, in scientific work, as I think this is generally acknowledged. At the core of science is the interplay between theory and empirical investigation. Scientific enquiry uses logic to test out hypotheses and conjectures, and even well-established theories in new contexts. It uses deductive processes to draw conclusions from carefully designed investigations.



This depends essentially upon applying sound logic to draw rational conclusions as to whether observations can - *given all the provisos and caveats that enquiry necessarily involves* - be considered to offer support for, or alternatively to bring into question, theoretical propositions.



However, science is also a value-heavy enterprise.

Indeed, science has its own set of internal values relating to such matters as objectivity, open-mindedness, self-criticism, open-reporting (and, increasingly, open-source data), inviting critique and dialogue. As an example, scientific work is meant to be reported openly with sufficient detail to enable another researcher to repeat the work, and check on the reported outcomes. In practice, replication may not be so straight-forward - *and as science has a tacit dimension it is never possible to include every relevant detail in a scientific paper* - but *the principle* is taken very seriously.

So as one example, a researcher making good progress in a new field is not allowed to publish her work with some key details missing so that others cannot copy her methods, in order to retain her advantage in the field (as was sometimes the practice some centuries ago). If this were to be attempted, then journal peer review should judge that the report is incomplete, and more details are needed before publication can be recommended.

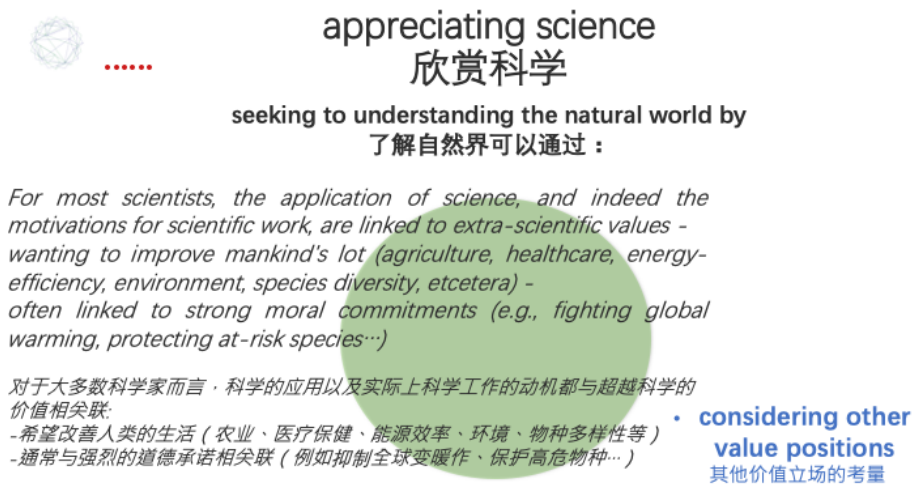
Science also adopts what might be referred to as aesthetic or stylistic values, relating to such issues as simplicity, elegance, symmetry, and the ability of new concepts to subsume different existing concepts (as in the case of Maxwell's electromagnetism subsuming electricity, magnetism and light) - or, of new principles that integrate different topics.

Many scientists were when young struck with awe and wonder - perhaps when looking at the night sky or at components of the living world, and this is often a factor in attracting them to science.

That young scientists may see beauty where others do not spot it - perhaps in the scales of fish, or the coloured patterns observed in an oily puddle, or the evolving shapes of clouds - or even in places others find distasteful - the magnified image of a fly with its compound eyes, or a dyed bacterium fluorescing under the microscope.

Critics sometimes claim that the scientist's cold analytical approach must dissolve the sense of beauty in nature. Scientists will often retort that understanding only adds to the sense of awe. Moreover, with greater understanding, scientists start to perceive beauty that others may not be able to access.

The symmetrical structure of the benzene ring has a profound beauty that is only appreciated when you understand and can visualise the molecular structure. False-colour images from satellites that observe the earth using different frequency bands to those supporting human vision reveal patterns of great beauty that no human could see directly (even from the international space station). In the story of the elucidation of the structure of DNA, scientists such as Rosalind Franklin and Francis Crick not only comment on the affordances of the structure (in terms of the genetic code, and replication of the nuclear material) but on its beauty.



For most scientists, the application of science, and indeed the motivations for scientific work, are linked to extra-scientific values. Scientists do not only go into science to better understand the natural world, but also to change it. They may want to improve crops, cure diseases, save endangered species, reduce waste, slow climate change, clear up pollution, lengthen productive life, and increase the quality of that life.

The choice to enter particular fields of research, or to seek funding for particular projects, may be informed by extra-scientific values as much as by the inherent value of the work. Science and technology are different disciplines, but of course applied science is the basis for new technology. We are all consumers of that technology, and we can all benefit, or suffer, from its consequences.

Of course, some scientists are happy to be paid to do interesting work, without regard to such considerations. So, for example, the military funds much scientific research and some scientists will happily work in areas such as weapons development, even in times of peace. Some may genuinely believe that such work helps keep the peace, or is necessary because their side is good and will only fight against evil. Others may not feel it is for them to be concerned.

Yet, no scientists today can be so naive as to consider they can ignore such questions and be absolved from moral responsibility for how the outcomes from their labour is used. This became very clear when the 1939-1945 world war was brought to an end by the use of atomic weapons such that a single bomb could destroy a whole city, and indiscriminately kill many thousands of people instantaneously, and leave thousands more to die painfully over periods of years afterwards, as happened at Hiroshima and Nagasaki. At the close of that war, many scientists became actively involved in working for international controls on the development of nuclear weapons. Modern nuclear weapons are so powerful that they use such atomic bombs as just the triggers of much more destructive devices.

As suggested earlier, awe and wonder, may be a major part of the motivation for working in science, and of the joy of the work. Just as important, science is a creative process.

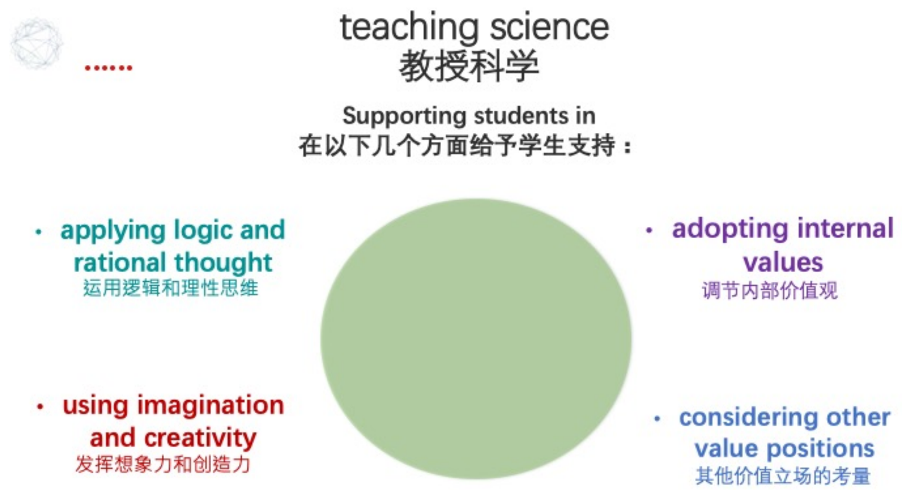
We now know enough about human cognition and learning to dismiss the idea that by observing nature, it impresses the truth of reality on us. Our brains impose patterns on our perceptions, and make sense of the raw data from our senses. Our realities are mentally constructed, and are never simple copies of the external world. Learning is an interpretative, incremental, and so iterative, process.

In other words, our understandings of the world are largely based on imaginative creations. Scientific theories and models and principles and laws do not exist in nature - they are all human constructions, as much as a painting or sculpture or ceramic artefact. Theories, like symphonies, may be inspired by nature, but are the creations of human imagination.

To the scientists, nature may offer beauty to match any human-produced art.

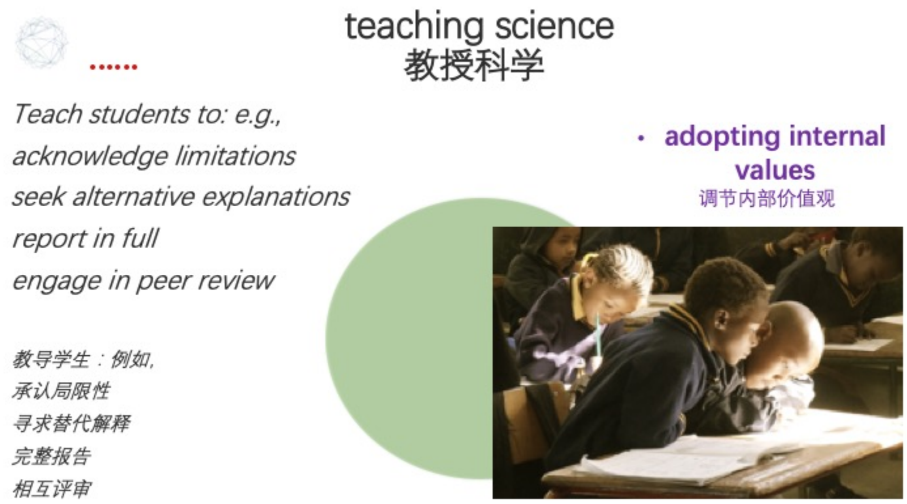
Of course, where science is very different from art, is that science seeks to build the constructions that most truly represent the natural world. So imagination is used to make 'guesses' at how best to make sense of phenomena, guesses that can be tested, and then also to construct the ways of testing these imaginings against nature itself. Yet even if imagination is used in a different role, it is just as essential to science as art.

Moreover, many of the inventions of science are not intended to literally reflect nature, but rather as thinking tools to imagine it. As one example, there are no magnetic lines of force in nature, but the invention of this way of representing completely invisible and non-substantial magnetic fields has helped generations of scientists in their work, as well as allowed others to appreciate the nature of magnetic fields. Another example is ray diagrams showing how light travels through lenses and off mirrors - these rays are completely imaginary. Non-scientists may not realise just how much science uses representational systems that are not intended to be realistic, but are purely tools of the imagination.



So, if a full appreciation of science needs to encompass values and aesthetics and imagination as much as logic, then any authentic science education must do the same.

Where science teaching includes a good deal of enquiry, and problem-solving, we can probably be comfortable that rational thought and logic are well represented.



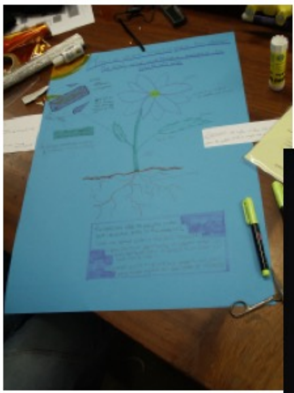
Enquiry also offers many opportunity to demonstrate and apply scientific values. Students can be taught to give full accounts of their work, including the relevant provisos and caveats that often limit the ability to offer strong conclusions. Students can be asked to report their work to each other and engage in peer-review (if in a supportive, constructive way, that perhaps is not always found in scientific professional practice). Credit can be given for finding the fault in one's own work and for being creative enough to suggest *more than one* possible interpretation of data.

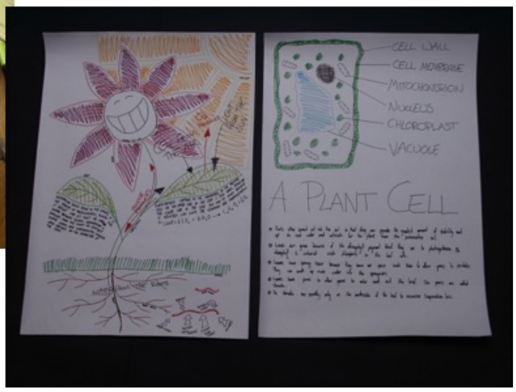
Engaging with what are known as socio-scientific issues can give students experiences of balancing different extra-scientific values when applying scientific knowledge. This will be important for all - people have to choose when to spend more on the food brand claiming more vitamins, or on the produce that claims to be produced in a more environmentally friendly way. People will have to balance the risks and costs of suggested medical treatments with likely benefits. It surely needs to be a core part of school science to offer some experience of facing such decision-making in the supportive context of the science class, before such issues are faced in adult life, sometimes with very high stakes.

Similarly, if science is a creative process that relies on imagination, then an authentic science education needs to reflect and represent this. Students must be given opportunities to use their imagination and be creative. This may sometimes involve writing stories or poems or undertaking paintings to reflect what is learnt in science; it may also mean using design flare as well as technical know-how in technology projects.

But it *also* means students need to be encouraged to suggest their own conjectures and hypotheses, to suggest their own explanations of scientific phenomena, and, if possible, ways of testing these. In practice, they will often have bizarre ideas (but then sometimes in science bizarre ideas may be useful - think of quantum mechanics and relativity), and it may not always be feasible to try out their tests. But that does not matter - often in science one scientist suggests ideas that others later test.

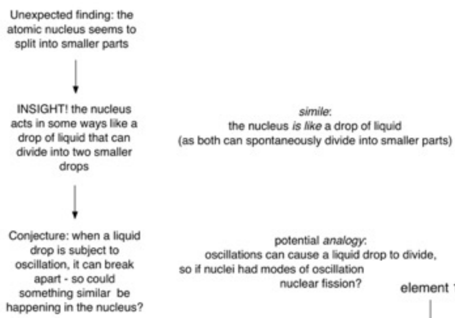
It may mean reversing the way some practical work is employed: rather than teaching scientific ideas that are answers to questions students never had, and then offering them demonstrations - get students to make their own observations of phenomena and suggest what is going on, why things happen. This may motivate them to take more interest in the theory or principle or mechanism they are then asked to learn about as it will have *epistemic relevance* (as it will respond to a meaningful question for the learners).

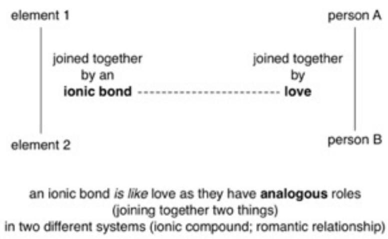




Taber, K. S. (2007). ***Enriching School Science for the Gifted Learner***. London: Gatsby Science Enhancement Programme.

Students should be encouraged to find creative ways of representing information they meet in science, and so bringing ideas together. This example is students' response to being asked to link ideas from biology, chemistry and physics in relation to plant nutrition.

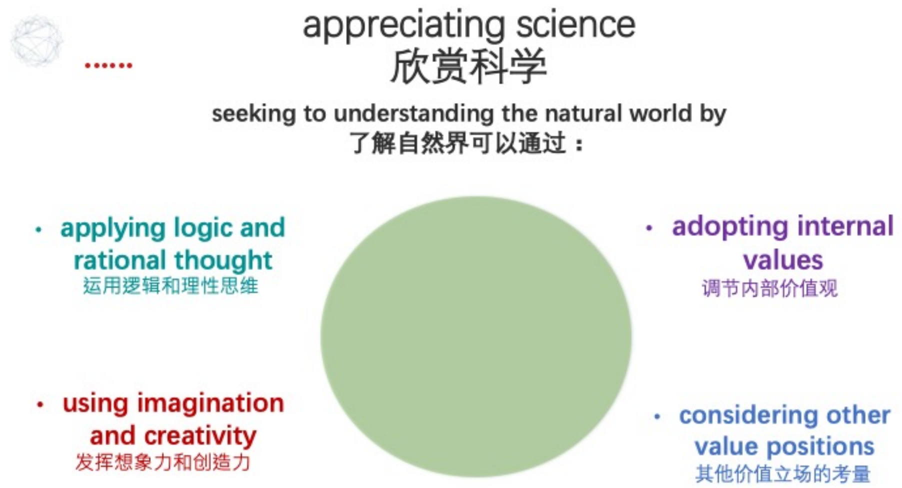




Taber, K. S. (2016). **'Chemical reactions are like hell because…' : Asking gifted science learners to be creative in a curriculum context that encourages convergent thinking.** In M. K. Demetrikopoulos & J. L. Pecore (Eds.), *Interplay of Creativity and Giftedness in Science* (pp. 321-349). Rotterdam: Sense.

Students can also be asked to develop their own analogies and metaphors and similes for scientific concepts. It is less important that these are technically accurate than they give a creative context for exploring ideas. Scientists themselves often use such devices both as thinking tools to develop their own work, and as communication tools to explain their ideas to others. These devices always have limitations, negative aspects, but exploring these can help in understanding the core of the scientific idea.

So, students can be asked to propose their own analogies, and similes, and then explain and defend them to others (as scientists need to do) and critique each other's suggestions in peer review (as scientists do).



These are just a few comments, but I hope I have left you with the idea that it is not only possible to link science with other areas of the curriculum concerned with values and creativity, but also to emphasise science's inherent values in the science classroom, and to build into science lessons activities which allow learners to experience the essential role of imagination and creativity in science.

Thank you.