Do we deal in knowledge in science lessons?

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As science educators, we assume that a major part of our role involves dealing with knowledge, but this is often not the case in school science lessons

ABSTRACT
If we accept the standard definition of knowledge as 'true, justified belief', then much of the subject matter of science lessons is not knowledge. Our typical classroom treatment of the visible spectrum is shown to fail on all three of these criteria for knowledge. An alternative view is presented in which pupils learn narratives from the scientific canon, just as they once used to learn stories from ancient Greek mythology. In both cases, the myths are useful schemata with which to analyse the world.

Knowledge

To begin with, I will spend a little time discussing the nature of knowledge – the subject matter of epistemology. A traditional definition of knowledge is 'justified, true belief'. This formulation, which goes back to Plato (*c*. 427 BC – *c*. 347 BC), demands that three criteria be satisfied if a proposition is to be accorded the status of knowledge. Firstly, the proposition must be **true**. If a purportedly factual statement made by us does not correspond with reality, then it constitutes not knowledge but false belief (or even deliberate deceit). Secondly, we must **believe** the proposition. If we do not, then our putative example of knowledge is merely empty words; to know something entails that we believe it to be the case. Thirdly, we must have a **justification** for holding a true belief. If it simply entered our head randomly, the accidental correspondence between our thought and the truth cannot be regarded as knowledge: it was merely a lucky guess. Each of these three criteria is a necessary condition for knowledge, and by failing on one or more of them our statement has failed the test of being knowledge.

This traditional account of knowledge is not without its flaws, as I shall show later, but it is nevertheless quite effective at ruling out unqualified candidates for the job of being knowledge. Three examples illustrate this: (a) a statement made by a fortune teller which, by a fluke, turns out to be correct [not justified]; (b) geocentric models of the universe [not true]; (c) fanciful theories that we are living in a computer simulation [not believed]. Any proposed knowledge-claim has only to fail on one of the three criteria for it to be rejected. However, this leads us to the uncomfortable conclusion that much of what passes for knowledge in the classroom and the examination hall must also be rejected. If we science teachers do not deal in true justified belief, we do not deal in knowledge.

The visible spectrum

Many of the statements for which we reward pupils when they say or write them are neither true, justified nor believed by them. For example, we might mark as correct the following statement written by a 15-year-old pupil: '*The visible spectrum consists of seven colours – red, orange, yellow, green, blue, indigo and violet*.' A moment's thought reveals that this is not true, however. There is an infinite range of wavelengths of light between red and violet, and hence an infinite range of colours, not the seven claimed by the pupil. One could object to my conflating wavelength and colour in this way, but even so there are clearly more than seven spectral colours. Although there are an infinite number of wavelengths between 380 nm and 740 nm, the average human visual apparatus can distinguish between colours separated by as little as 1 nm in the middle of the spectrum and about 10 nm at the two ends. Even the worst-case scenario (10 nm colour-resolution) would thus yield 36 discernibly different spectral colours between violet (380 nm) and deep red (740 nm). Experienced dyers and colourists claim to be able to distinguish – by eye – between about 10 million colours, but this would include the various tints (such as the pinks, which combine red with white), shades (which have varying proportions of black pigment) and non-spectral colours (combinations of spectral colours, for example the browns). The general point also works with lights as well as dyes: pupils will see pink rather than red if some ambient white light in an imperfectly blacked-out lab falls on a patch of red light.

Further investigation reveals just how flimsy is the pupil's justification for her assertion. She did see a colourful patch on a sheet of paper when she pointed a ray box at a prism in a darkened lab last year, but this was not very compelling evidence and certainly did not cause her to make her present statement about the seven colours. She could not discern the difference between indigo and violet, for example, and assumed that the teacher's unwillingness to class it all as just shades of purple must have originated in his more refined 'scientific' awareness of colour. (In fact, the physics teacher [me] is colour-blind, as attested by his choice of clothes.) The third failure of her statement in meeting the criteria of this tripartite theory of knowledge involves belief. The pupil does not really believe that there are only seven colours. The song '*I can sing a rainbow*' mentions pink and she can see no reason why this colour should not be on the approved 'scientific' list. However, it receives no mention in the 'Richard of York Gave Battle In Vain' mnemonic (Box 1), so for examination purposes she decides to suppress her personal beliefs and toe the party line. The statement she writes on the exam script fails on all three of our criteria, so it cannot be regarded as knowledge. Failing to meet even one of the criteria is enough to reject a statement from the category 'knowledge'.

Ivan, a Russian émigré GCSE physics pupil of mine, first alerted me to the arbitrary nature of our labelling of the spectrum. He identified two colours which English-speaking pupils saw as one: *Siniy* (blue) and *Goluboy* (light blue), so his rainbow has an extra colour. A member of the Dani tribe of New Guinea, on the other hand, would have identified only two colours – *mola* (bright colour) and *mili* (dark colour) – according to the work of Rosch (1972). However, this variation may only reflect linguistic convention, rather than perceptual differences. After analysing colour terminology across 20 languages and 98 cultures, Berlin and Kay (1969) showed that there are eleven 'focal' colours – white, black, red, green, yellow, blue, brown, purple, pink, orange and grey – and that these universally recognised colours have a biological basis. Some relate to retinal rods and the magnocellular (black and white), whilst others are associated with opponent process cells and the parvocellular (red, yellow, green and blue). These focal colours are compared by Berlin and Kay to 'canonical views', an idea I develop next in a slightly different way.

BOX 1 Sources of pupil 'knowledge'

Q. The phrase '*Richard of York gave battle in vain*' is commonly used to help pupils remember the seven colours, but where does it come from?

A. Claimant to the English throne, Richard, Duke of York, was defeated at the battle of Wakefield in 1460 – a key moment in the Wars of the Roses – and hence '*gave battle in vain*'. Shakespeare tells the story of this battle in *Henry VI part III*.

Q. Who is responsible for the song '*I can sing a rainbow*' which has led astray generations of pupils studying science?

A. Arthur Hamilton wrote '*I can sing a rainbow*' to be sung by Peggy Lee in the film *Pete Kelly's Blues* (1955). Hamilton also composed the classic Julie London song '*Cry me a river*' (1955), subsequently recorded by Ella Fitzgerald, Ray Charles and Dinah Washington, and so he can be forgiven.

Origin of the speeches

How then, do pupils come to speak and write such dubious examples of 'knowledge' as the girl produced in her traditional ROYGBIV account above, and why do we treat them as correct? A somewhat provocative answer might be that their behaviour as pupils, and ours as teachers, is adaptive in the Darwinian sense. Initially, this conjecture seems to be counter-intuitive. In early hunter-gatherer society (the page in our history during which evolutionary psychology suggests that our epistemic virtues were written) the holding of false beliefs was not conducive to survival. Maladaptive notions about the benevolence of sabre-toothed tigers, for instance, would tend to shorten the lives of any individuals holding them, and would thus be selected against in the harsh milieu of that era. In the ecology of the school system, however, beliefs are not tested against nature 'red in tooth and claw' but in the light of the approval (or the withholding of approval) of teachers and examiners. It is a reasonable survival strategy for pupils to learn the approved version of the colours of the spectrum – together with many other examples of received opinion in school science – rather than try too hard to develop an alternative analysis of their observations. We reward this compliance fulsomely, and those pupils who are astute enough to realise this thrive and succeed in the school environment, by adopting canonical views for examination purposes. This is not a genuine adoption however. Pupils often only engage with these orthodoxies to the extent of using them in school contexts: they do not embrace them and take them fully into their existing families of schemata. Stefan Ramaekers (2001), echoing Nietzsche, rather harshly labels our part in this as '*Teaching to Lie and Obey*'. Instead of being the honest brokers of scientific knowledge we thought we were, we are simply initiating our pupils into a cultural heritage, in which a familiarity with ROYGBIV is on a par with knowing the words to the nursery rhyme '*Ring-a-ring of roses*'. Neither has any claim to involve truth, but both are embedded in 17th-century history: Newton's experimental work and the plague respectively. (The children's rhyme begins with the first symptoms of the plague – the '*ring of roses*' on the skin – and ends with the death of the victim: '*They all fall down*'.)

Feyerabend (1987) puts this historical dependency of science well:

> *The formulae that adorn our textbooks are temporarily frozen parts of activities that move with the stream of history.*

Our self-view as honest brokers of scientific knowledge is under threat if we accept the argument so far. One possible riposte is to attack the tripartite theory of knowledge upon which the argument depends, and the work of Edmund Gettier (1963) has spawned an entire philosophical industry in attempting to do just that. Gettier does not help us in our present quandary, though, for his examples exclude even more claimants to the title of knowledge: propositions which pass the test of being 'true, justified belief' but can be shown not to be knowledge. We want to proceed in the opposite direction and find ways of shoe-horning the things we teach back into a working definition of knowledge. If we can't do this, we must simply admit that much of our subject matter has no legitimate claim to being knowledge.

Redefining 'knowledge'

We can perhaps begin this process by re-conceptualising 'true', 'justified' and 'belief'. Beginning with 'true', we can set out to find an alternative to a straightforward 'correspondence' view of truth – that is, the commonsense view that the statement 'The snow is white' is true if it really is the case that the snow is white. This may even be a desirable re-conceptualisation. We have no direct access to reality itself (Kant's *noumena*) but only to our own perceptions and conceptualisations of reality (*phænomena*), so we cannot check for correspondence between (a) our view of things as they seem to be, and (b) things as they actually are, irrespective of our view. When we say 'The snow is white' we are making a statement about appearance – about our perceptions and conceptualisations – because that is all we have to go on. To make a truth-claim about our statement would require us to access directly things as they really are and to compare this actuality with our statement about appearance. However, if we had the gift of direct access to things 'as they actually are', we would not need to compare them with things 'as they seem to be', so the notion of correspondence is redundant. Since we are not blessed with omniscience, we try in vain to establish a correspondence between two realms, only one of which we can enter: the realm of things as they appear to be.

A possible replacement for the correspondence model is the 'coherence' view of truth. By this, we mean that statements are taken to be true if they fit coherently into our pre-existing network of beliefs. This is not a fixed web, though: we are usually willing to modify some of the beliefs in our network, in the light of recalcitrant empirical evidence. For example, pupils will eventually give up their notion that plants draw 'food' from the soil if they have enough experience to the contrary – perhaps including the growing of mustard and cress on damp blotting paper. Others concepts are much more difficult to shift though, securely enmeshed as they are at the centre of our personal webs of belief. Having said this, even our cherished belief in non-contradiction (that something cannot both be and not be at the same time) is under attack from uncomfortable results in quantum physics.

The need for justification can similarly be modified. Rather than insist on an empirical determination of all claims to knowledge (which is both unworkable in practice and not needed if we accept the web-of-belief model underlying the coherence theory of truth), we could claim to be entitled to accept normally reliable sources of knowledge at face value. It is impracticable always to put all putative 'facts' to the empirical test, and we hope that our pupils are willing to concede that, fallible as we are, most of the statements we make as teachers can be trusted.

The final modification is to the 'belief' requirement of the tripartite definition. The so-called 'diffident schoolboy' objection is that a pupil may not have a secure knowledge of (say) the chemical symbol for lead, but may still write down 'Pb' in response to an examination question, without being sure whether or not this is the correct answer. During the exam post-mortem with his friends, they remind him of the slightly risqué way in which their chemistry teacher helped the class to remember this particular symbol, and he now has a firmer claim to this knowledge. The significant point here is that at the time he was required to demonstrate his knowledge the diffident schoolboy hadn't been so sure, and he had written the correct answer down with little confidence. During the exam, he didn't really believe in his answer, so he was arguably not in full possession of this bit of knowledge. To sidestep this famous objection, we can simply apply an operational definition to school knowledge: '*School knowledge is that which is demonstrated in exams*'. The feelings of the pupil do not come into this definition, so a person scoring well in a chemistry exam is deemed to have good chemistry knowledge, irrespective of the degree of confidence with which the questions were answered.

We have dissolved the original problem by re-framing our view of what constitutes school scientific knowledge, but it leaves me feeling a little uncomfortable. Does it you? On this new construal, truth is what fits comfortably into our conceptual schemata, justification can come from accepting the word of an expert and pupils need not believe what they write down in exams.

Beyond the spectrum

I have spent quite an amount of time showing that the traditional school science narrative about the colours of the visible spectrum fails the tripartite criterion for knowledge. It may be argued that we need only stop re-telling this particular myth and we can once again claim to be dealing in knowledge, since the rest of the stories we tell in school science are perfectly reasonable. Unfortunately this is not the case, and a few minutes' thought reveals the unwelcome presence of spurious 'knowledge' throughout school science. In chemistry lessons, for example, I, along with many other members of our profession, have told pupils that '*everything is made of atoms*'. This is an extremely suspect ontology, excluding as it does fields and electromagnetic waves and – less obviously – thoughts and numbers. In physics, the solar-system view of atoms we teach to younger pupils is not literally true (although it has some justification in terms of its explanatory power) and is rightly not believed by many pupils, except as a way of earning credit in exams. In biology, more controversially, evolutionary theory is not believed by large numbers of pupils in the United States (and a sizeable minority of children here in Northern Ireland). Similarly, in geological discussions about the evidence for the age of the Earth from radioactive decay data, some fundamentalist Christian pupils will insist that Archbishop Usher was correct in dating the Earth's creation as 4004 BC and that the scientific evidence is flawed, or has been put there by the Devil to test our faith.

How are we as teachers to deal with the problem of these, and other, instances of the concepts with which we daily do business, being either untrue, unjustified or disbelieved by our pupils?

This is not a simple question, but it is one that we should address as teachers. One possible solution to our problem is to adopt a post-modernist stance towards knowledge. There are many stories out there that purport to be 'truths', but there is no grand narrative that can justifiably assert a claim to being 'The truth'. School science is just one narrative amongst many. Paul Churchland's (1988) point that '*the warmth of the Summer air does not feel like the mean kinetic energy of millions of tiny molecules but that is what it is*' is a misleading contrast between two descriptions of reality, of which the scientific version is deemed to be the correct one. There is no incoherence in accepting both descriptions as correct, or indeed embracing a third model involving probability-waves rather than particles. We ought to be honest about this and let pupils see that although science has made some spectacular advances over the past few centuries, it is not the only story to be told. All pupils – of whatever religious persuasion – should know the key components of secular western science, as parts of an important narrative that has useful explanatory power. We are the storytellers who can bring these fables alive and stage-manage our pupils as they play their roles, engage with the props and improvise around the script. We need to make it clear that school science is a cultural phenomenon with many oversimplifications and is merely a staging-post on a journey to a fuller understanding of the beliefs of the scientific community. These beliefs, in turn, are not infallible and are frequently changing in the light of new evidence and theoretical frameworks. Paradigm-shifts occur every so often that require the textbooks to be re-written.

Usefulness of our fables

There is no harm – indeed there might be some value – in learning that the colours of the spectrum in decreasing order of wavelength are red orange yellow green blue indigo and violet. It may not, strictly speaking, be knowledge, but it is a tried and tested little anecdote in the set of tales that comprise school science: a snippet of learning that is easy to investigate in the lab, easy to learn, easy to test, and easy to expand into a fuller account of wave theory as the pupils become more scientifically sophisticated. In times gone by, a classical education was valued greatly in the West, so Greek myths were the predominant stories amongst the educated. They could be used as tools for thinking, and their truth or otherwise was largely unimportant. For example, Homer's myth of Mentor is relevant in education even today:

> *Mentor was an old friend of Odysseus, to whom the king had entrusted his whole household when he sailed, with orders to defer to the aged Laertes and keep everything safe and sound.*

We apply this idea of a trusted friend who provides wise counsel for a less experienced protégé (Odysseus' young son Telemachus) to the widespread present-day practice of having qualified teachers supervise student-teachers on school placement. The classical notion forms a narrative 'peg' upon which we can hang our contemporary stories, and in recognition of this we call the experienced teacher 'the mentor'. We can then unpack Homer's story a little more and consider the extent to which Mentor (the goddess Athene disguised in human form) allowed his protégé Telemachus to make his own mistakes and hence learn from them: an important judgement to be made when we guide student-teachers.

The myth of the spectrum can similarly be unwrapped. Pupils begin by seeing an undifferentiated whole: the rainbow. Next, they discriminate between the colours and split the spectrum into seven bands – a convenient chunk of information to assimilate. Later, they come to appreciate the idea of a continuum of wavelengths of which any subdivision is arbitrary. This snippet becomes a tool for thinking, and the idea of a spectrum is one that can be applied outside its laboratory context. For example, we now talk of some pupils as '*being on the autistic spectrum*', rather than as '*being autistic*'. We recognise that this disorder can vary in extent and we initially identify four levels (similar to our splitting the spectrum into seven colours): (a) high functioning/Asperger's (b) mild (c) moderate (d) severe. The next stage in the degree of conceptual sophistication is the recognition that, like the visible spectrum, the autistic spectrum encompasses an infinite range of severities. Every child is a unique case. Knowing the myth of the visible spectrum has helped us to refine our thinking about the autistic spectrum: from an undifferentiated whole to a series of infinitesimal increments.

So, to return to the question originally asked, do we deal in knowledge in science lessons? The answer can be 'yes we do', as long as we adopt a broad view of 'knowledge' and recognise that our scientific stories take their place alongside other myths, including the tales told by teachers of other subjects and the narratives of popular culture.

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