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Beliefs about science and beliefs about language

Clive Sutton [a]

[a] School of Education, University of Leicester, UK

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Beliefs about science and beliefs about language

Clive Sutton, School of Education, University of Leicester, UK

Researchers have recently shown a growing interest in teachers' and pupils' beliefs about the *nature of science*, and how these differ from the picture offered by historians, philosophers and sociologists. Tacit beliefs about how scientists work are, however, sustained by unexamined assumptions about language, and this paper explores those assumptions and suggests that attention to beliefs about the *nature of language* would be a productive focus in future research and in efforts at curriculum reform. A key tension is that between the learner's experience of language *as an interpretive system*, actively used for generating new understanding, and of language *as a labelling system* for transmitting established information.

Introduction

School science, it seems, has been misrepresenting the nature of science for decades. There is an allegation, or at least an implication, in recent research reports and critiques, that school experience is responsible for the persistence of views (variously characterized as 'inductive realist', 'naïve empiricist', 'Baconian', 'positivist', or 'scientistic') which help to maintain an inadequate public understanding of the scientific enterprise and a degree of alienation from it.

From enquiries into pupils' beliefs, we are told that their dominant image involves a cumulative series of 'discoveries' (seeing what is there) in which 'facts' (which had previously been overlooked), are unearthed by individual scientists who then simply *report* them in language which requires very little argument. Thus, Driver *et al.* (1993, 1994) suggest that many British pupils have little or no understanding of the social institutions of science and the processes involved in achieving a scientific consensus. These pupils think that controversy is settled just by gathering more information, getting more 'hard facts'. Duveen *et al.* (1993) claim that 'experiments' and 'theory' are somewhat disconnected in pupils' thinking, with a consequent misunderstanding of what 'an experiment' is, and Ryan and Aikenhead (1992), reporting their use of the VOSTS schedule (Views on Science–Technology–Society) with thousands of Canadian pupils, noted that for an item that concerned the status of theories as 'discovered' or 'invented', three-quarters of the pupils chose statements related to the 'discovery' view. Within such a scheme of thought, what else could language be but a plain commentary on the new discoveries, with words having a fact-describing function, rather than a theory-constituting one?

As for the teachers, their own espoused beliefs about the status of scientific knowledge and the manner in which it changes appear to be in flux. Koulaidis and Ogborn (1989) claimed that, amongst the teachers whose views they elicited, as compared with those in earlier surveys, there were more who professed a degree of instrumentalism (scientific knowledge is what works, rather than what is 'true' in a permanent sense), and with this there was also a greater awareness of the role of models. Pomeroy (1993), using a category she called 'traditional, Baconian, logicoempiricist', reported that in Alaska teachers appear *less* traditional than research scientists. Lakin and Wellington (1991, 1994) were cautious of over-interpreting their results to indicate any particular philosophical stance in the British teachers with whom they worked, and remarked that many of these had had little opportunity to reflect about the nature of science and the consequences for their own practice in school. Soon afterwards, Nott and Wellington (1993) offered a simple activity for teachers to encourage reflection and discussion about such matters. Many of the 114 VOSTS items (Aikenhead and Ryan 1992) can also be used for that purpose.

Powerful arguments have also been formulated on theoretical grounds, by writers who have tried to articulate the consequences of three decades of scholarship in science studies. The insights of historians, philosophers and sociologists call into question some of the taken-for-granted routines of school science and although there is not room here for a complete review of the theme, a recent one is given by Kelly *et al.* (1993). They characterize science as 'a socially constituted enterprise shaped at many levels by human values, beliefs and commitments', and they write of 'working to incorporate a post-empiricist philosophy of science in schools'. Selley (1989) complained of the pervasiveness of the assumption in school 'that scientific truth pre-exists its discovery', and of the idea 'that there is a simple logical path from evidence to theory'. Since neither of those beliefs has survived the critical scrutiny of historians or philosophers, schools were, as he saw it, badly out of date. Earlier statements on related lines were made by Duschl (1988), Hodson (1988) and Nadeau and Desautels (1984) and they are extensively explored in Millar's book (1989) *Doing Science: Images of Science in Science Education.*

Human ideas, controversy, consensus

Arguments continue to rage about just what are the most important activities of scientists, and how these are influenced by the contexts in which they work, so it would be unwise to advocate that a particular account should be taught as an orthodoxy about *the* nature of science, especially if it were cast in terms of various -isms and -ologies that are in danger of taking on the character of terms of abuse. There are, however, many points of which the historians and sociologists have made us more acutely aware, yet which have been neglected in school. Here are two:

(1) Scientific activity is an activity of human beings. New ideas are stated by human beings. A tendency to neglect that human authorship, with extensive use of phrases like 'It has been discovered that', rather than 'Rutherford first suggested that...' could constitute a serious misrepresentation.

(2) Most new scientific ideas go through a stage when they are to some extent 'on trial', tentative, even contentious. They are understood at this stage as 'claims', meriting discussion as well as attempts at replication, and are not to be simply *accepted.* It is only after a more or less extended process of scrutiny within the scientific societies that some of them gain a wider acceptance and become a part of 'public knowledge', and at that stage they are retrospectively described as 'discoveries'. A tendency to neglect the tentative stage in school presentations, and to offer only the end-product as a set of uncontroversial 'findings', is a misrepresentation. Phrases like 'It has

been found that...', which are necessary shorthands in the research community, obscure a key part of the process of establishing what people will agree has been 'found'.

Both these points suggest that we should be cultivating in the classroom a much greater sense of the human voice behind the major scientific ideas, and of the argumentative struggles involved in establishing them. Setting aside for a moment the traditional arguments about detaching scientific knowledge from particular individuals in order to emphasize its hoped-for universality, and the traditional myths about impersonal expression being necessary for 'objectivity', re-humanizing could be the key to a better representation of science, as well as to developing in pupils a greater sense of their own involvement. It is certainly central to a reappraisal of the role of language in science.

The active interpretive voice of the scientist

At the start of new thought, the language of a scientist is always personal and human, and clearly the product of a living breathing personality. The signs of personal involvement may be held back or disguised at various times, especially where a writer has to be on guard against potential critics, but they are not difficult to find. Consider the following passage, written by Robert Boyle in the 1660s (figure 1). At that time he was one of the founders of the Royal Society, a leader in building a community of investigators amongst whom 'matters of fact' would be distinguished from mere speculation, but his own mind was constantly active in speculating about what was going on: 'Does air really exist as a stuff?', 'Is it continuous, or might it consist of little "corpuscles"?', and so on. In 1660 he had published *New Experiments Physico-Mechanical, Touching the Spring of the Air and its Effects; Made, for the most Part, in a New Pneumatical Engine*. Notice how the word 'spring' serves to focus attention on the one particular aspect of air to which he was attending–its squashiness in an enclosed vessel. With this word, and its companions 'elastic' and 'elastical', he initiated a whole new branch of scientific conversation.

The abbreviated extracts in figure 1 are from material which he wrote sometime in the same decade, summarizing his speculations about what might account for the springiness (Hall 1965). The third paragraph is bracketed off in an attempt to isolate some of the difficulties we have with 17th-century terminology, if we do not easily envisage his work-room with its bottles of 'corrosive menstruums'.

There are many features of this passage which are important in a reassessment of the role of language in science. For example:

1. It is personal; there is no doubt about the human voice–a real person is putting forward these ideas.
2. This person makes full use of figurative analogy as he imports images and words from other areas of experience to try to make some sense of the squashable air.
3. The approach is speculative, but it is also tentative–at times even apologetic, lest the speculation seem too great. This combination is actually a powerful strategy of *persuasion*. We are invited to go along with various possibilities, yet the author never has to risk any of them as his own definite opinion.

A mixture of that kind is probably fundamental to the processes of communication, persuasion and counter-persuasion which occur in scientific groups in any age, and

Of the structure of the elastical particles of the air, divers conceptions may be framed ... for one may think them to be like the springs of watches, coiled up, and still endeavouring to fly abroad. ... One many also fancy a portion of air to be like a lock or parcel of curled hairs of wool; which being compressed ... may have a continual endeavour to stretch themselves out, and thrust away the neighbouring particles ...

I remember too, that I have, among other comparisons of this kind, represented the springy particles of the air like the very thin shavings of wood, that carpenters and joiners are wont to take off with their planers ... And perhaps you may the rather prefer this comparison, because ... these shavings are producible out of bodies, that did not appear, nor were suspected, to be elastical in their bulk, as beams and blocks, almost any of which may afford springy shavings...

(...which may perhaps illustrate what I tried, that divers solid ... bodies, not suspected of elasticity, being put into corrosive menstruums, ... there will, upon the ... reaction that passes between them in the dissolution, ... emerge a pretty quantity of permanently elastical air.)

But possibly you will think, that these are but extravagant conjectures; and therefore ... I shall ... willingly grant, that one may fancy several other shapes ... for these springy corpuscles... Only I shall here intimate, that though the elastical air seem to continue such, rather upon the score of its structure, than any external agitation; yet heat, that is a kind of motion, may make the agitated particles strive to recede further and further ... and to beat off those, that would hinder the freedom of their gyrations, and so very much add to the endeavour of such air to expand itself.

And I will allow you to suspect, that there may be sometimes mingled with the particles, that are springy, ... some others, that owe their elasticity, not so much to their structure, as their motion, which variously brandishing them and whirling them about, may make them beat off the neighbouring particles, and thereby promote an expansive endeavour in the air, whereof they are parts.

Figure 1. Robert Boyle speculates about the reasons for the 'spring' of the air.

if we disguise it or ignore it in school, the classroom experience will continue to be a misrepresentation of what scientists do.

Boyle's language is theory-constitutive, and not a simple reportage, even in the third paragraph, where he tells us of his laboratory experience, for it's there that he captures an important new idea with his phrase 'permanently elastical air'. Having brought 'divers solid bodies' (chalk and limestone for example?) into contact with various 'corrosive menstruums' (such as oil of vitriol, perhaps?), he tells us that he had noticed the production of 'a pretty quantity of permanently elastical air'. Now this was long before the general acceptance of Van Helmont's newly invented word 'gas', or the naming of different 'gases', so it was no easy matter for Boyle to interpret or describe what was going on. The phrase 'permanently elastical air' helped him to do so. It was a precursor of the plural 'elastic aeriform vapours' which became the standard term in the 18th century for what we now, so easily, call 'gases', and it was a very important expression in making people aware of such materials and able to discuss their behaviour more precisely. It lasted longer than some of his less successful speculations, but the important thing to notice is that in this relatively more 'objective' paragraph, as well as in the speculative ones, he is searching for suitable words and images to focus his own thought and that of his readers.

Another point of interest is that some of Boyle's images are mildly anthropomorphic, as he plays with the idea of corpuscles or particles 'brandishing' and 'whirling' with an expansive 'endeavour'. Watts and Bentley (1994) argue in favour of humanizing school science by deliberately reviving/allowing anthropomorphic and animistic thought. They note that many teachers feel uneasy about admitting to such speech, but there is surely no need for us to be apologetic about forms of expression which resemble those used by scientists in their creative effort. The developing language of science is full of such expression, even if ideas are later restated in more sober terms. Scientists derive their new ways of talking about a topic by drawing upon the imagery available to them in their times. Two hundred years after Boyle, John Tyndall wrote *Heat Considered as a Mode of Motion* (note again the tentative '*considered as*'), and from the language of his day he took some strikingly military turns of phrase to develop his mental picture of what was going on in an expanding pig's bladder full of air, and in his Turkish bath (my emphasis in the following extracts). His context was a teaching one, to persuade a larger audience of what he and his colleagues had already accepted about heat and motion, but this exploration of imagery is more than just a teaching aid:

> According to our present theory [the expansion of the bladder] is produced by the *shooting* of *atomic projectiles* against its interior surface ... the impression one receives on entering the hot room of a Turkish bath is caused by the *atomic cannonade* which is there maintained against the surface of the body.

Elsewhere in the same passage Tyndall writes of the '*discharge* of particles', and of an effect 'causing ... the particles within to *concentrate their fire*'. This was only a few years after the Battle of Balaclava, and the phrase 'atomic cannonade' would have been particularly evocative, but (sobering the image later) Tyndall and other scientists do of course eventually disown words like 'shooting', and emphasize that they wish to speak only of a mechanical rebounding. For a history of the hostility towards incautious speech, despite its central importance, see Sutton (1994).

Scientists as generators of new ways of talking

The popular image of science presents language as a medium for describing—for getting an account of the world as it is, an 'objective' record of what happens, independent of human beings. Yet in the examples given so far it is more of a tool for trying out ideas, for figuring out what is going on, for interpreting the situation. To reconcile the two views we have to understand that there is a progression in scientists' writing, beginning with the first tentative claims of a researcher and ending, some years or decades later, with the textbook of established public knowledge. The functions of language at these two stages are different. While ideas are still fluid, the language is very much an active, flexible tool of thought, i.e. 'language as an interpretive system' as shown in the left-hand column of figure 2. Later on there is an established body of knowledge, and much less doubt about how to express it. Words then seem to stand as labels for definite things, and I have called the language at that stage, especially if we don't know its origins, 'language as a labelling system' (the right-hand column). A proper understanding of science requires an awareness of both, even though it is common to associate science with only the right hand column.

LANGUAGE AS AN INTERPRETIVE SYSTEM for making sense of new experience	**LANGUAGE AS A LABELLING SYSTEM** for describing, reporting and informing.
• is clearly the product of a person who is saying: "I think that...", or "It seems to me that..."	• is apparently independent of a person's voice:
"I began to think whether there might not be a motion, as it were, in a circle" - William Harvey about the blood, 1628. *"It has not escaped our notice that the pairing we have postulated immediately suggests a possible copying mechanism for the genetic material." - James Watson & Francis Crick, about DNA, 1953*	*"Copper turns black when heated"; "Metals are always discharged at the cathode"; "The volume of a fixed mass of gas is inversely proportional to the pressure"; "Under the influence of a gravitational force, planets move in elliptical orbits"; "Air molecules are in constant motion".*
• is analogical or metaphorical : "This is like a... " or "It's as if...." or "We could think of it as...."	• appears to be direct and literal rather than imaginative."These are the facts...This is how it is.."
• is tentative, imprecise at first, and flexible in trying different ways to capture the same idea.	• is definite, precise, needing the right word for the right thing.
In communicating we appear to be:	*... or in this case to be:*
PERSUADING others towards a new point of view, building up a new community of thought.	**TRANSMITTING** knowledge, increasing the recipient's store of information.

Figure 2. Two conceptions of language.

We are, in some ways, correct to associate science with the right-hand column. The collective effort of scientific communities does generate universal statements about 'volumes', 'pressures', 'cathodes', 'elliptical orbits' and 'molecules' which belong to everyone, and which we can regard as timeless truths independent of any particular person's opinion. The desire to confine science in that right-hand column, however, has been caused by over-exposure to these near-certainties, without the doubt that scientists experienced when first formulating them, and my case is that this sustains the picture of easy fact-finding as the basis of science. The desire to confine is also partly the result of an over-enthusiasm to separate the 'opinions of a person' and 'the facts of nature', and we ought to be more respectful of opinions. Take William Harvey's comment about the blood, in the left-hand column of figure 2. Like Boyle, he writes with a personal and interpretive tone to offer his new opinion: 'I began to think...'. Notice also the conscious newness of the image, and the tentative way in which he offers it: 'a motion *as it were* in a circle'. This was an altogether new way of talking about the blood, closely connected with a new way of seeing in his mind's eye what might be happening, and it had exciting consequences for practical investigation. The interaction of these three aspects is fundamental to innovation in science (figure 3).

Harvey had seen in his imagination a possible return route to the heart, and he wondered about the peripheral tissues, which seemed to be 'spongy' (Harvey 1628). He was already thinking of the blood 'draining' out of 'the obscure porosities' of the sponge into the veins, from where it might go back to the heart, constantly refilling the chambers, and his words became for him theory-constitutive, guiding his attention and further effort. He realized the relevance of measuring the capacity of

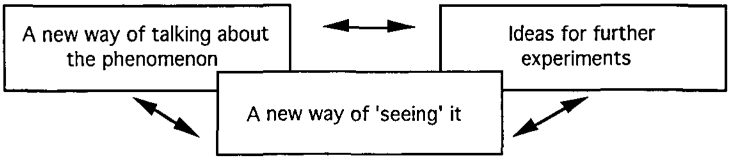

Figure 3. Interaction of talking, 'seeing' and experimenting.

the heart chambers, and estimating how much blood is pushed out at each beat. Having done so, he calculated the throughput, and that became a crucial part of his argument that there must be a continuous circulation. He also attended more closely to the spurting from cut arteries, and wondered further about the valves in the veins. The image and the way of talking shaped what he attended to and what he chose to investigate.

It is hard for us to know what it might have been like without this way of seeing, talking and thinking, because we inherit what has become the 'obvious' way to discuss the human body. We speak easily of a 'circulation', and also of the heart as a pump, but before the time of Harvey that system had not emerged. It would have been more usual in the 1620s to see the heart *as a spring or source* of 'vital spirits' which then went out to irrigate the landscape of the body. Harvey himself wrote of the heart in terms of political and domestic economy–the 'sovereign of the body' and the 'inmost home' where the blood could recover 'its state of excellence and perfection'. The move to later mechanical alternatives was made much easier, however, by his shift of perception, captured in the famous sentence: 'I began to think whether there might not be a motion as it were in a circle'. A few of his own expressions were more overtly mechanical; for example he wrote of the blood from the lungs 'carried ... into the aorta as by two clacks of a water bellows to rayse water' (Harvey 1616)*.

A new choice of words, a new metaphor, was coming into use. In effect, a way of talking which was already well established in the context of hydraulic engineering was starting to be applied in the totally new context of the human body. With it came a new way of seeing what was going on, and it gave a powerful stimulus to enquiry as people applied their understanding of pipes and pumps to a consideration of the workings of the body. One of the first additional outcomes was Malpighi's identification of 'capillary' channels ('hair-like' channels) in the tail of a tadpole. They evidently linked arteries and veins. Older ways of talking about the blood and the heart then began to fall into disuse, and when Descartes elected to see the whole human body as a set of mechanisms, circulation-talk and pump-talk became the standard mental tools.

From this and similar examples, we can say that radically new scientific insights involve re-descriptions of the phenomena being studied, using language not previously applied to that topic. They depend on language imported from some other

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* The use of the water-bellows' imagery with its 'clacks' (leather valves) comes from lecture notes which Harvey wrote in 1616 and is quoted by Eric Neale (1975) in *William Harvey and the Circulation of the Blood* (London: Priory). Most of the quoted phrases are from chapter 8 of Harvey 1628—English translation by R. Willis (1847; repr. 1965 by Johnson Reprint Corp.) *The Works of William Harvey*.

area of use, in an attempt to figure out what is going on; they depend, that is, on metaphor. All around us we can find the results of similar switches into new ways of seeing, and the talk-systems which go with them: 'charges' 'flowing' along a wire; 'fields' of influence around a magnet; 'pathways' of successive chemical reactions in a cell. Each of those systems in its turn has provided extra points for scientists to investigate. Talking about 'heat' as a fluid which can flow into and out of objects is a particularly interesting example, because the basic idea has now been superseded, but it was a highly productive branch of scientific conversation in its heyday, and it led to the development of units for a 'quantity of heat', and to the concept of varying 'capacities' for heat in different materials (their 'specific heat capacity'). It is still very much with us, in expressions such as 'heat flow', 'thermal capacity' and 'heat sink'.

Metaphoric re-description need not be hidden from school pupils. We can ask them 'How did anyone come to talk like this? What were the scientists who chose these particular words trying to say? What image did they have in their mind's eye?' We can revive the signals of tentativeness which accompany new thinking – the 'as if...' and '... as it were...', and Harvey's 'I began to think...', and show pupils that scientific ideas have been formulated by real people struggling for appropriate words. Analogies, similes and metaphors were not extras for them, but a key part of their thought. It is with the help of such devices that scientists come to think, see, talk and act in new ways. A usual pattern is for the suggestive metaphor to be elaborated into a model from which testable predictions can be derived. Pupils should appreciate that pattern of working and, if they do, the idea of language as only a labelling system will not arise.

Reinstating figurative language makes the conventional distinctions between 'figurative' and 'literal', between what is 'metaphorical' and what is 'factual', no longer tenable, for as we shall see, the one fades to become the other. Many members of the scientific community have tried to maintain a demarcation between metaphor and science (Sutton 1992, 1993), but not everyone has done so. Here is Michael Faraday, writing to a colleague about the importance of 'poetic' thought in his science (Faraday 1845):

> You can hardly imagine how I am struggling to exert my poetical ideas just now for the discovery of analogies and remote figures respecting the earth, sun, and all sorts of things – for I think that is the true way (corrected by judgment) to work out a discovery.

All new language is poetic and metaphoric in the first instance, as Faraday suggests. A new image offers a possible new way of making sense of something, which can then be subjected to judgement and criticism and experimental test of predictions. All new language is interpretive and, in a group of human beings, it is for comparing and sharing interpretations, attempting to gain some agreement about how we perceive things. It is communicative in the sense of trying to produce *a community of thought*. It is persuasive in the sense of inviting others to share a particular view. Where, in the development of school science, did we lose this sense of a communicative and persuasive medium?

How the sense of human involvement fades

Scientists do not stop at the point of formulating a new thought. Their very human statements are scrutinized, checked and passed on by others until the human 'voice' of the individual investigator is gradually lost. What began as a figurative interpretation and an attempt to persuade us into a new point of view is transformed into labelling language – a literal description simply to be transmitted to us. If school pupils are on the receiving end of such transmission all the time, they may never 'hear' the active interpretive voice of the imaginative scientist at all. That is why we should be including in school science more about the scientific societies and research networks, and how they build up a consensus about what shall count as reliable knowledge. Science today is understood as a semi-cooperative social enterprise for the production of such knowledge, and participating in congresses or writing articles, reviews and books are recognized as being just as much a part of science as are the practical activities of handling apparatus and designing experiments. Writing is especially important, and it is in the writing of successively 'firmer' kinds of publication that we find and a gradual obscuring of the human agency, and a change from 'persuading' to 'informing' (figure 4).

Researchers publishing for the first time know very well that there is persuasion to be done before any of their ideas will be accepted as part of 'scientific knowledge', and they prepare their case accordingly. The more novel the idea, the more careful they have to be, helping others to take it up and get comparable experience at the laboratory bench. That is usually a clinching argument, which will push a mere 'claim' by one human being towards the status of an established 'fact'. It becomes no longer just 'So-and-so's idea' or suggestion or interpretation, but something worthy to be called 'So-and-so's discovery' and eventually 'something we all know'. In a journal article the new content is still provisional, but later it may be cited alongside other researchers' claims in a review or a research handbook, and eventually in textbooks. That signals greater acceptance by the research community,

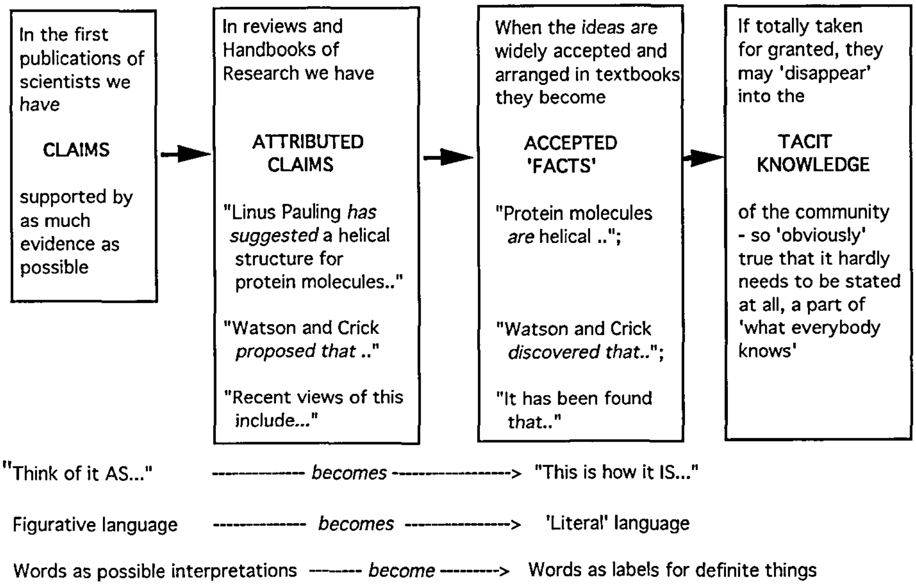


Figure 4. Changes in language and in the status of knowledge as an area of science matures, and tentative ideas are transformed into firm facts.

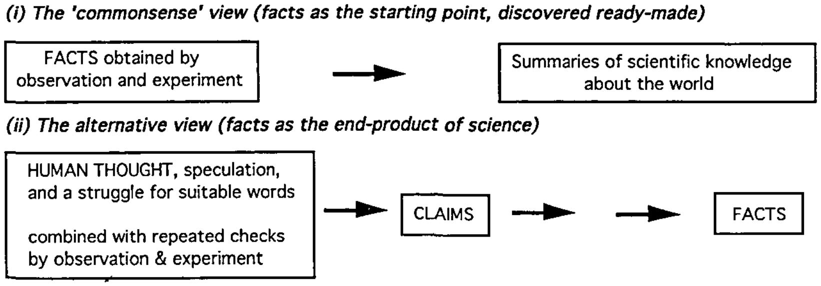
and phrases such as 'It is thought that...' or 'So-and-so has suggested that...' are gradually reduced or omitted. In other words a conversion process goes on, in which some of the ideas and claims of individuals are built into the structure of thought of a larger community and converted into agreed public knowledge which merits the status of 'fact', or 'fact for the time being', or at least 'best available theory, which to all intents and purposes we can assume to be correct'. For this account we are much indebted to those who highlighted the significance of the sequence of different kinds of publication: Journal → Handbook of research → Textbook. One of the focusing events was the production in 1978 of an English translation of Ludwik Fleck's book *The Genesis and Development of a Scientific Fact*, with an introduction by T. S. Kuhn (Fleck 1935, 1978). Since then there have been a number of systematic attempts to compare the linguistic features of the writing at each stage, and a helpfully short account is given by Myers (1992), based on his study of modern examples of scientists' writing. He notes several changes, which are clearest in the contrast between journal articles and finished textbooks. From the differences he mentions, I select three:

(1) a loss of qualifying phrases (or 'hedges' as he calls them), such as 'it appears that', 'perhaps', and 'the suggestion of...';
(2) a change in purpose of personal pronouns (in journals these mark the newest part of the authors' claim, which might be disputed; in textbooks they signal a didactic stance where the writer is guiding the reader to the accepted view, rather than offering anything on which there might be more than one view);
(3) a marked reduction in the number of references cited to support what is stated (indicating a different attitude from what is required in persuading the reader).

In the middle stage of Fleck's three-stage process, the writers of handbooks and reviews sift and relate a range of different claims. Some they reject or neglect, and others get bound into a general structure of thought which works as a guide to further research. Once ideas have become embedded in that way it no longer seems necessary to refer them back to the original authors every time, for they are felt by then to have some universal validity, independent of where exactly they arose or who first put them forward. The more often they are used, the more familiar they become, and the less tentatively they are expressed, so words inevitably start to function as labels for the things that people now feel sure about. A phrase like 'the orbit of the electron', which began as a mere figure of speech, becomes a label for a reality which to all intents and purposes is considered to exist (or in this case *was* so considered for some years after the planetary model of the atom was suggested!). It would not be possible to have fast conversations about any new ideas without treating some of them in this way, and familiarity engenders reality. School pupils who do a lot of science will also have to speak in that way, but a crucial point is whether they ever get enough sense of the interpretive origins of the terms to avoid a misunderstanding of their status.

The sequence of figure 4 contrasts markedly with the 'common-sense' view of science, in which facts are thought of as the starting point, as shown in figure 5.

I am suggesting that it is the firmness with which we use 'factual' language in school that leaves learners with the impression that the scientists go out to 'discover' facts in the natural world, by doing things and 'seeing what happens', rather than by any process of imaginative effort and painstaking construction. Facts seem to have



(i) The 'commonsense' view (facts as the starting point, discovered ready-made)

(ii) The alternative view (facts as the end-product of science)

Figure 5. Two ideas about a scientific fact.

been there all the time, and the role of the scientist was just to go out and find them! Textbooks offer the product of science not as *an interpretation* at all, but as a 'simple' account of how the world is, just as if it had been read off directly from Nature. Statements such as 'Atoms contain protons, neutrons and electrons' or 'Air consists mainly of two gases–nitrogen and oxygen' give little indication of human intervention, even though most of the words in them are relatively recent inventions, and were the object of considerable debate and controversy before they became an accepted part of current science.

The control of controversy in scientific communities

Another important way in which the presentation of 'facts' in school becomes misleading arises from a change in the generality of statements as time goes on. The early writings of scientists include accounts of something done *at a particular time and place*, where *a known person* did a certain thing. Such accounts are of intense personal interest to other researchers but, later, they get replaced by statements which aspire to a universal validity and are no longer about specific times, places or people. In a recent discussion of 'the one right way to talk science', Lemke (1990) suggests that the imitation of these universals, 'cut off from the here and now, and from human action', is one of the ways in which classroom language becomes dull and alienating for some adolescents. We should show these pupils that such statements were not universal at their inception, and help them to empathize with the interpretive effort and argument which the scientists experienced.

It is in connection with potential controversy that the 'textbook knowledge effect' connects with another de-humanizing influence–the taught routines for laboratory reports. Methods of controlling controversy are important for the success of scientific societies, and the basic techniques were developed in the 17th century, by people like Robert Boyle. They learned to write in such a way as to separate any challenge to their experimental procedures from more fundamental challenges to their schemes of thought. In some of the learned societies it was customary that accounts of experiments would be 'received' in the society's meeting but not discussed at that point, to emphasize their status as reports rather than arguments. In the learned journals, a structured format was developed so that authors could keep the unarguable separate from the arguable. There have been several important studies of the 17th century which chart the rise of this literary technology (Shapin and Schaffer 1985, Vickers 1987, Bazerman 1988, Dear 1991). These authors show

how the new natural philosophers grew in confidence at setting down 'matters of fact' which could be accepted either on the authority of witnesses or on the authority of a written account which allowed vicarious 'attendance' at the experimental event. As this kind of writing developed there was a degree of disownment of the personal voice, pre-empting rejection with the suggestion that 'It is not I who says this, but my equipment'. Such an asserted 'matter of fact' is not quite the same as the achieved '*fact*' already discussed as the outcome of a longer negotiative process, but it does resemble it in apparently being read from the Book of Nature, rather than conjured by the observing scientist. By such means, the members of the learned societies found that they could prevent premature disintegration of the group into factional controversy, and collaborate over what they *did* agree about.

Gradually, the craft of writing a high proportion of your claim in the less contestable areas of 'method' and 'results', clearly separate from 'discussion', became a part of training, especially after the professionalization of science in the 19th century. That is how schools came to inherit a discipline for writing up accounts of benchwork in as detached and 'objective' a way as possible, holding back acknowledgement of one's own thought. If such methods were ever justified, it was only in the context of training technicians in the routines of laboratory life, and from today's perspective we can see that the approach can be dangerous in allowing a misunderstanding of how scientists work. Nowadays children are encouraged to write more about their own thoughts and expectations before an experiment, but that does not mean that they necessarily understand the personal and interpretive basis of scientific thought, if the whole language ethos of the classroom suggests otherwise. 'What do you think will happen?' is a valuable question to children, but to reflect *my* analysis we also need something like: 'So-and-So thought... Is that a good idea? Why would they have thought it, and what kind of evidence would they look for?'

The pupils' experience of how language is used

So far, I have tried to show that science is a communicative activity amongst human beings. Investigators are personally involved in putting forward their ideas and finding ways to support them. They have a definite desire to share and compare ideas, but processing of those thoughts in the research community results in a loss of personal authorship, the fading of active metaphors, and the production of universal statements made by no one in particular to no one in particular, purporting to be true in their own right. Science becomes information to be received, rather than ideas to be discussed.

In school we hope that our lessons will be an opportunity to share and compare ideas, and probably we all succeed, sometimes, in pushing the products of science back so that they become again a set of exciting ideas open to discussion, but the sheer quantity of apparently inert information can hinder our efforts, so that pupils get a very different kind of experience. Sometimes they hear us using language very flexibly, with a strong interpretive tone:

> What's happening on this pond then, when the insect skates around so lightly without falling through and getting wet? It's as if the surface were a kind of stretchy skin. Look carefully, and you can see it dented where the legs are. Do you see what I mean?

At other times they meet statements which are hardly at all 'unpacked', masquerading as simple truths about the world rather than the products of human imagination and thought:

> The needle is held up by the surface tension of the water.
> Air pressure makes the can collapse.
> Light is always bent when it goes from one medium to another.

My argument is that, when the proportion of the latter is too high, they get the impression that language is a labelling system, and that communication is transmission rather than sharing of interpretation. They come to expect the transmission mode of the left-hand column of figure 6, and are ill-prepared to use their own language interpretively to re-express in their own words what the scientists meant. With such a limited sense of what language is for, and lack of experience in actively using it, they carry too simple an idea of science as fact-gathering and of language as fact-labelling, and they can become increasingly disadvantaged as learners. It is therefore very important that a language policy should be developed in school to prevent that happening. It is through a language policy that we might give a better insight into the nature of the scientific enterprise, and improve the capability of learners, so they are less likely to cast themselves in the role of passive receivers of information. Figure 6 shows further points of contrast in experience and belief. It is developed from the distinction made by Douglas Barnes between language for transmission and for interpretation (Barnes 1976). This time 'labelling' is on the left to reflect the suggestion that this may be the first and main impression which pupils get in their science lessons.

Recovering the interpretive voice

A school language policy sets guidelines about the kinds of reading, speaking, listening and writing that pupils are entitled to experience. Many features of such a policy–for example, writing for audiences other than the teacher as assessor of knowledge–were outlined over a decade ago in the 'language across the curriculum' movement. At that time they may have seemed to be just the enthusiasms of language teachers, but today we can see that they also constitute good science, and from that point of view a language policy should have components about scientists' language, teachers' language and pupils' language:

(1) Teachers should present the language of scientists as a human product, so that when pupils listen or read, they are conscious of a human author. Other sources as well as textbooks should be used, and the thought behind a particular choice of words should be explored–the emphasis all the time being on what these people thought and why they thought it, not just on 'what we know'.
(2) They should make a point of using their own interpretive voice in reworking such language, deliberately putting it in different ways, and cuing their pupils to do so as well. They should show that there are always alternative ways of phrasing an idea, and put everyday expressions and technical terms together, to discuss how well they succeed in capturing a particular idea.
(3) Teachers should attend to and encourage the interpretive voice of the pupil, and should respond person to person, so that it is clear that language is a medium for conversation about ideas, not just for receiving 'the truth'.

A suitable approach, which makes the language of scientist, teacher and pupil more obviously a personal expression of thought, is to turn the lesson into a critical discussion of a scientific 'story'. The attention of the pupils can be focused on the

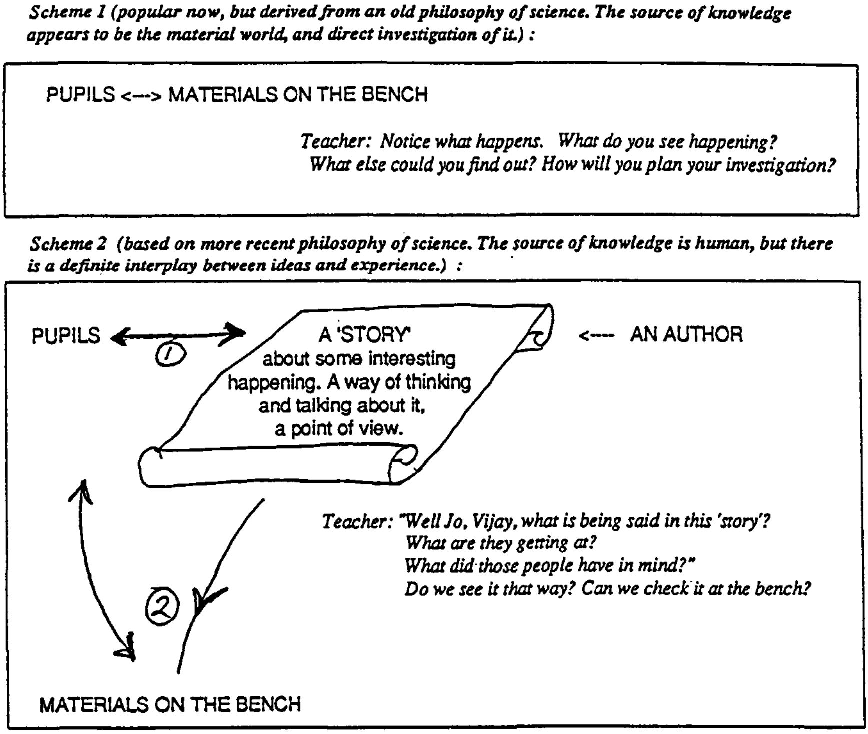
	LANGUAGE AS A LABELLING SYSTEM	LANGUAGE AS AN INTERPRETIVE SYSTEM for making sense of experience
1. What the hearer or reader thinks he or she is doing	Receiving, noting, accumulating	Making sense of the other person's intended meaning.
2. What the speaker or writer appears to be doing	Describing, telling, reporting	Persuading, suggesting, exploring, figuring, teaching.
3. How language is thought to work in learning	Clear transmission from teacher to learner is needed; the teacher's speech is very important.	The main process is the active interpretation and re-expression of ideas by the learner; the learner's speech is very important.
4. How it is thought to work in communication generally	Like Morse Code in a wire, or packets in the post.	The important part is how you decode the Morse, or unpack the parcel and use the pieces it contains. What the hearer constructs may approximate to the speaker's intention, but communication is always partial.
5. How it is thought to work in scientific discovery	We find a fact and then find words to describe it.	We choose words which influence how we see the new point of interest, and how we can then talk about it .
6. What language seems to do vis a vis the world of Nature.	Words correspond in a simple way to features of the external world, and generally there is one correct word for one thing.	Words highlight features to which we are attending, and so they steer thought and dialogue. Whether to call a lion a carnivore, a hunter or just a big cat requires a speaker's decision for a particular context.
7. Assumptions about the meanings of words	They have a fixed meaning, at least for a particular context; a definition will capture the meaning.	Meanings vary from person to person as well as from context to context. Meanings are in minds rather than on paper, and even where definitions serve well there is always some residual ambiguity.
8. Assumptions about longer statements	If well worded these are unambiguous and clear to all.	Meanings are always debatable, and require an interpretive effort by the hearer or reader.
9. The essence of communication	**TRANSMISSION**	**PERSUASION**

Figure 6. Two conceptions of language as pupils encounter it in school.

story of the circuit, the chemical reaction, the water supply of the plant, or whatever the topic is. We can present the story as a statement which is open to discussion as well as experimental test, and offer it as the ideas of scientists (or one particular scientist) about this circuit, this reaction, this plant root, or whatever.

In recent years school science has often been conducted as if it were a study of Nature directly, rather than a study of what people have thought and said about Nature, but real scientists always attend to other people's stories before heading for their laboratory benches. They think and discuss, and propose and argue. When they go to the bench, they do so in order to seek constraints on the arguments, reasons for preferring one view to another. They do not go there passively to receive the truth, however strong the conviction, sometimes, that one is 'reading the Book of Nature'. In many cases it took decades to work out a satisfactory way-of-seeing-cum-way-of-talking (especially about electric circuits or chemical reactions), and this point is hardly acknowledged if modern pupils are sent to the bench to 'describe what you see' or to 'say what happens'. Instead of directing pupils to the bench (Scheme 1 in figure 7), we should be getting them to think more about the ideas and suggestions of some author, known or unknown (Scheme 2).

Although Scheme 2 places practical work in a secondary position, I do not wish to imply that science lessons should never start by handling materials. Often it is tactically better for pupils to handle something, then to meet and reflect about the 'story', and then return to the bench. The story, however, and conversation about



Scheme 1 (popular now, but derived from an old philosophy of science. The source of knowledge appears to be the material world, and direct investigation of it.) :

Teacher: Notice what happens. What do you see happening? What else could you find out? How will you plan your investigation?

Scheme 2 (based on more recent philosophy of science. The source of knowledge is human, but there is a definite interplay between ideas and experience.) :

A 'STORY' about some interesting happening. A way of thinking and talking about it, a point of view.

Teacher: "Well Jo, Vijay, what is being said in this 'story'? What are they getting at? What did those people have in mind?" Do we see it that way? Can we check it at the bench?

Figure 7. Two conceptions of a science lesson.

it, should be the core of the lesson, with the practical providing a feel for the phenomena as interpreted in the story.

What sort of things will suffice as a 'story'? It does not have to be in narrative form. Even an extract from a textbook could do, as long as we can stimulate a sense of authorship, an image of some person or people who have put forward the idea. The story might occasionally be in the original words of a scientist, as with the examples I have already given (Boyle would be too difficult for many youngsters, but Harvey would not). Sometimes the story might be an account by a pupil–possibly from one of last year's exercise books. Often it will be in a spoken rather than a written form, and come directly from the teacher:

> What's happening in this circuit? This is how I imagine it. Listen and think, then talk and try ... and then report whether you agree, whether you see what I mean, and why or why not.

Occasionally a story might be more deliberately provocative, for example a newspaper cutting with an outrageous scientific misunderstanding. Important features of a story are:

(1) it should be up for discussion and reflection, not just for acceptance;
(2) it should be presented as the product of a person the pupils can visualize;
(3) we should expect them to empathize and respond in the form
'I think that what So-and-So meant is ...'.

If these features are present, pupils have an incentive to respond with their own expressions of thought, and a dialogue can be achieved in which scientists' accounts gain the status of 'successful story' or 'best available story'. A communicative basis for the lessons is established. Of course many teachers do achieve just such a dialogue in their *informal* classroom interactions, despite the weight of syllabus content and transmissive tradition. Their pupils know from experience that the function of language is persuasion, and they become better at re-expressing ideas for themselves and at writing with sense-making intent, rather than in a regurgitative mode. 'Marking' strategies matter at that point, because the teacher's response to their explanations is crucial in maintaining the communicative effort (Benton 1980). The teacher becomes a correspondent rather than a corrector. Scheme 2 of figure 7 is thus intended to articulate what some are doing already, but which is not institutionalized as a part of people's expectations of a science lesson. Formally, school science is not at present an examination of ideas, but is said to be about 'doing' things, learning from practical experience, and finding out for yourself. For a variety of reasons teachers accept these doctrines, even though they are aware that some pupils do not pick up as much as was hoped from their 'hands-on' experience. Yet at the very time (in the UK) that the national curriculum threatens to ossify the 'learning by doing' approach and make it compulsory, studies of how scientists actually work are showing more powerfully than ever that 'experiments' are not their first and not always their main activity. Experiments only make sense within a new framework of talking which guides the design of the experiment and the manner of its interpretation. It follows that if pupils are either to plan an experiment or to make sense of one, they must thoroughly 'understand the story' within which it is embedded.

Pointers for research

We need to know more about how pupils use language when they try to re-tell in their own words the story within which a particular investigation is situated. The re-telling task should invite them to explore the thoughts of other people, to consider not only their own way of seeing the phenomenon, but also how they believe others have seen it. It should encourage exploration of the link from human intention to action in science.

We ought to examine the pupils' sense of what they themselves do with language in their science lessons, what they think their teachers are doing with it, and of course how they imagine scientists use it. Do pupils have a sense of language as an instrument of scientific creativity? Do they have a sense of it as a tool in their own learning? We could look carefully at how teachers and pupils speak about practical work (the facts emerge directly from experiment or observation?). We could explore what learners infer from the language of textbooks (an unproblematic description of how things are?). We could ask them about the authorship, as they understand it, of major theoretical ideas, or about the origins of new words, and the relationship of these words to 'opinion', 'theory' and 'fact'. We could observe how much provision is made in lessons for exploration of ambiguity or alternative interpretations. More directly in the area of the nature of science we should explore the varied, and sometimes unexamined, meanings of 'discovery', 'fact' and 'theory', as all these three words should probably be used with greater care.

Whether for research purposes or in the context of curriculum reform, it is important to reassess the traditional notion of a 'scientific' language which seems to be different from that in other areas of life. This notion has detached 'knowledge' from 'people'. Belief in it is a by-product of the success of the scientific community in taking what actually were human expressions and converting some of them into agreed 'public knowledge'. The styles of both journal and textbook were and are important in that process, but they are neither appropriate nor necessary as the main medium of exchange in school. A much wider range of ordinary human language, including narratives, would give more pupils access to science, and a more accurate picture of how scientists work.

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