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Science Without Literacy: a ship without a sail?

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ABSTRACT *This article argues that reading, writing and argument are central to any conception of science as it is currently constituted. Moreover, it is through the texts of science, popular accounts or journalistic reported versions that the majority of the public interact with and consider the implications of the findings that science presents. However, the study of the language of science, science's epistemic base and the cultural norms and values that underpin its practice are currently considered only marginal to the teaching of science. Rather, the specialised laboratories provided for science teachers and the narrow conception of science embodied in the curriculum gives pre-eminence to science as an empirical activity in the naive belief that this is central to understanding the nature of science. The consequent failure to recognise the centrality of language, literacy and argument to science education leaves the majority ill equipped to become critical consumers of science. Change requires a concerted attempt to reconceptualise the priorities for science education through a mix of new curricula, new strategies and last, but not least, new modes of assessment.*

INTRODUCTION

What does it mean to 'do science'? In common parlance, people study history, geography or English but it is rare to hear anybody talking of 'doing history'. This difference reveals, I believe, a significant demarcation between enquiry in science and the humanities. A difference that is embodied in the *ancien* cry of the Nuffield curriculum developers that school science should offer the opportunity to 'be a scientist for a day'. Its lingering influence is still seen in the American National Standards (National Academy of Science, 1995), where it is argued that students at all ages should have the opportunity 'to use scientific enquiry and develop the ability to think and act in ways associated with enquiry'. Such statements would appear to suggest that the core feature of learning science is practical activity, one which involves maximal 'doing' and minimal 'reflecting', activities which, in contrast, are associated with discourse and argument. The classic stereotype of the scientist portrays him (as opposed to her) as an individual surrounded by a plethora of test tubes, potions and equipment (Mead & Métraux, 1957; Driver *et al.*, 1996). The image is one of action, an individual engaged in manipulating the material world, exploring and exposing its inner secrets, but not one of discourse, i.e. reading, writing and

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communicating science. For the school pupil such images are substantiated by the fact that science, in common with design and technology, music and drama, has a specialised location for its teaching, one that supports and enables practical manipulation of the material world.

Yet, it is my contention that such images are self-sustaining delusions (Barthes, 1972), in essence tacit myths that are uncritically accepted by the practitioner community as they appear, at least superficially, to carry a self-evident logic. Put simply, because the professional scientist and the science teacher both share a common locus for their activity, the laboratory, they likewise share a common rationale and activity, that of *doing* science. However, such a belief ignores the self-evident fact that, whereas the scientist's laboratory does support genuine open-ended empirical enquiry, the laboratory of the science teacher, in contrast, supports, first and foremost, a *pedagogical* function. In this article I wish to begin by arguing for a different and better understanding of the pedagogical purpose of empirical work in the teaching and learning of science, an analysis that recognises the limitations of practical work. I then seek to show that a core feature of science is that it is a cultural activity undertaken through the medium of language. Thus, if we wish students to gain insights and understanding of the manner and nature of scientific reasoning, we must offer them opportunity to use and explore that language, i.e. to read science, to discuss the meaning of its texts, to argue how ideas are supported by evidence and to write and communicate in the language of science. As currently practised, a major obstacle to the learning of science is the failure to recognise the centrality of language activity to science and, as a corollary, the implications for its teaching.

THE LIMITS OF THE LABORATORY

The role of the laboratory in school science has been explored in numerous books and articles (Woolnough & Allsop, 1986; Hodson, 1990, 1991; Woolnough, 1991; Osborne, 1997, 1998; Millar, 1998; Wellington, 1998; Leach & Paulsen, 1999). Perhaps the most original contribution is offered by Millar (1998), who sees the primary role of the laboratory as essentially serving a rhetorical function, one in which the materials and equipment are critical adjuncts to the science teachers' basic task of persuading his or her pupils of the validity of the scientific world view. Millar examines several standard school science experiments and asks critical questions of their purpose. What, for instance, he asks, is the implication of the failure to obtain the expected outcome of starch tests on leaves kept in the dark? Does this really pose a challenge to the accepted scientific account? Clearly the answer is no. For it would take substantively more than the failure of any single experiment, particularly one conducted with the limited facilities and controls offered by the school science laboratory, to undermine the consensually agreed explanation. Rather, Millar sees the essential purpose of practical work as one of producing the phenomenon, 'to get things to work as expected'. As such, the phenomenon then becomes a vital piece of data to buttress the claims advanced by the science teacher that, for instance, the rather ordinary and unexceptional leaf is, instead, a chemical factory capable of transforming simple molecules into complex carbohydrates at room temperatures and pressures, a process which humans cannot replicate. Practical work undertaken by pupils advances the teacher's rhetorical case one step further, becoming, in effect, autodemonstrations carrying with them the implicit message that 'our understanding and consequent control of materials and events is so good that I (the teacher) don't even have to do it for you but you can do it yourself.' (p. 26). This insight offered by Millar's analysis is further supported by Nott and Smith's research, which reveals the extent to which teachers will 'rig' or 'conjure' the material world to behave in the manner they describe (Nott & Smith, 1995). For whilst the failure of any single experiment does not undermine the teacher's belief in the consensually agreed account, it does undermine *their pupils' belief* in the scientific account, which now depends for its acceptance on the epistemic authority of their teacher rather than their own first hand experience of the phenomenon itself. In short, seen from this perspective, the function of the laboratory is to provide a theatre in which the scientific world view can be enacted.

Secondly, the opportunity to engage in 'hands-on' manipulation of the material world is something which is greatly valued and enjoyed by pupils. Research exploring pupils' attitudes to science consistently reveals that one of the major points of engagement with science is practical work (Osborne *et al.*, 1996; Osborne & Collins, 2000; Reiss, 2000). For instance, in our own work we found that it was valued by pupils because: (i) it made scientific concepts more transparent enabling retention, essentially an identification of their rhetorical function; (ii) it provides a vital opportunity for personal autonomy where the pupil has at least some opportunity to act independently on their own initiative. Given that Paris (1998) has identified that control is one of the four requisite components that underpin the motivation to learn, the others being choice, challenge and collaboration, it is perhaps unsurprising that practical experiences are deployed by science teachers as a valuable motivational tool and become a predominant feature of pupils' experience of school science.

More fundamentally, there are good educational and epistemic reasons for providing opportunities for students to engage in empirical enquiry. Interactions with the material world are essential sensori-motor experiences for forming the constructs and referents which populate the language of science (Piaget, 1953). Referents to perceptible macroscopic phenomena enable the individual to construct the metaphorical pictures necessary to envisage the microscopic entities that are only accessible through instrumentation (Harré, 1986). Thus the cells of an onion are like bricks in a wall, electricity is like water in a pipe, atoms are packed like oranges on display at a supermarket and more.

Yet science is much more than empirical work in the laboratory. For many scientists, such as the cosmologist, the theoretical physicist or the epidemiologist, their work requires no engagement with the *process* of data collection as it requires the activity of modelling and theorising, elements which are also central to 'doing' science. Indeed, our understanding of science has shifted significantly during the past two decades towards a view of science that recognises that there is a social dimension of knowledge construction that involves conjecture, rhetoric and argument (Taylor, 1996). This perspective acknowledges that observations are theory laden (Hanson, 1958; Kuhn, 1962) and, therefore, that it is not possible to base claims for truth on observation alone. Rather, claims are seen to be grounded through the process of argument, relating the imaginative conjectures of scientists to the evidence which is available, evidence which itself needs to be open to scrutiny to examine its conceptual underpinnings and its reliability and validity. Such a process requires scientists to engage in both reading the work of others *and* writing to communicate their own findings. In short, to engage in the discourse of the scientific community. Thus, science is a complex interplay of phenomena, data, theories, beliefs, values, motivation and social context both constituted by, and reflected in, its discourse (Longino, 1990; Giere, 1991; Cole, 1992; Thagard, 1994).

THE CENTRALITY OF LANGUAGE

Giere (1991) presents a useful, though simplified, model to represent the ways in which reasoning and argument come into the processes of establishing scientific knowledge claims (Fig. 1). As the models shows, establishing a knowledge claim in science involves more complex processes than making generalisations from observations of the world through induction. There is the process of establishing what counts as data, through conducting and checking observations and experiments. Then deductions are made from the conjectured theory through reasoning and calculation. The extent to which the data agree, or disagree, with the prediction then needs to be examined, a process which is rarely straightforward. Rather than a single theory or conjecture to be checked, it is often the case in science that there are two (or more) competing theories. Then the key activity of scientists is evaluating which of these alternatives does, or does not, fit with the available evidence and, hence, which presents the most convincing explanation for a particular phenomenon in the world. Such activity is not done in the laboratory, but in the papers they write and read, the E-mail messages and faxes that fly between institutions and in the presentations and arguments engaged in at conferences. Central to such activity is the requirement to be literate in science. For such specialised discourse, knowledge of its content is a necessary condition but not sufficient, for sufficiency requires an ability to talk, read and write science. Literacy from this perspective is not a mere adjunct for the storage and transmission of information. Rather, as Norris & Phillips (2001) state, literacy becomes *constitutive of science itself*. For just as there can be no houses without roofs or windows, there can be no science without reading, talking and writing. And it is only these activities that will allow the learner to transcend the gulf that exists between knowing what is technically correct and having the competence and understanding 'to say the "right" thing at the "right" time and in the "right" place' (Gee, 1996)

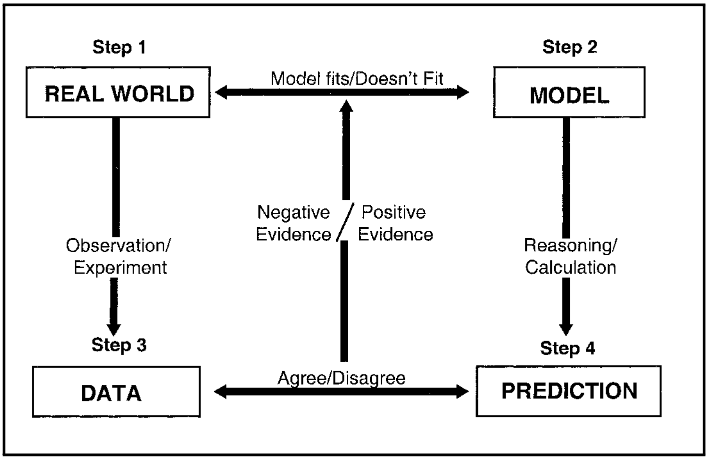

FIG. 1. Giere's (1991) diagrammatic representation of the interaction between reasoning, theory and argument in the development of scientific ideas.

A similar view is articulated by Postman & Weingarter (1971) when they argue:

> Almost all of what we customarily call 'knowledge' is language, which means that the *key to understanding a subject is to understand its language* [emphasis added]. A discipline is a way of knowing, and whatever is known is inseparable from the symbols (mostly words) in which the knowing is codified. What is biology (for example) other than words? If all the words that biologists use were subtracted from the language, there would be no biology. ... This means, of course, that every teacher is a language teacher: teachers, quite literally, have little else to teach, but a way of talking and therefore seeing the world.

Or, in the words of a scientist himself, science requires the individual to make:

> some of these bone-headed arguments and having them picked apart by your fellow students and professors, you start to hone your ability to develop an argument. ... The other thing I would say that worked for me I suppose came from the writing in itself. From writing scientific papers and arguments. (Hogan & Maglienti, 2001, p. 679)

Moreover, there is now a large and growing body of research showing that there is a significant distinction between the epistemic reasoning of scientists and non-scientists. These include the failure to test hypotheses systematically, ignoring critical variables, trying to produce effects rather than explain them and interpreting data in a biased manner to support prior beliefs (Kuhn *et al.*, 1988; Schauble, 1990; Dunbar, 1994; Hogan & Maglienti, 2001). Whilst some of this research has been the subject of significant criticism for its failure to consider the reasons why individuals respond to anomalous data in the manner they do (Chinn & Brewer, 1993, 1998), for its flawed model of science inherent to its methodology (Koslowski, 1996), or to recognise that the epistemic standards of the non-scientist 'need only meet the standards of pragmatic precision in everyday life' (Hogan & Maglienti, 2001), the rationality of science is secured by its commitment to evidence and argument as a *modus vivendi* (Siegel, 1989). At the core of science, then, is a belief that assertions need to be justified and alternatives considered. Exposing non-scientists to such norms and the criteria that underpin scientific discourse is an essential component of developing *any* understanding of the cultural practices that constitute science (Gaon & Norris, 2001). And as a socio-culturally defined group, such practices are carried out through the discourse practices of the community (Gee, 1996; Wenger, 1998), through its conferences, its journals and *through its languages*. In short, that writing and arguing are core activities for *doing* science.

LANGUAGE IN SCIENCE EDUCATION

In contrast to the recognised role of language in science, the common conception amongst many science teachers is that the discourse of science is essentially transparent and that language offers some unique ability to represent the physical world in an unambiguous manner (Lemke, 1990). From such a perspective, the primary difficulty associated with science is merely the acquisition of complex mental concepts and the mental processing required to develop understanding (Shayer & Adey, 1981). Implicit in such a view is a correspondence theory of language often coupled with a naive realism, both of which are positions that have long been philosophically questioned. For the thread that runs from the work of Saussure to Wittgenstein to the latter day social constructivists is that language can only be understood in the context of its use. Moreover, a corollorary of this cognitive view, albeit a simplistic interpretation, has been an emphasis on education as a process of transmission where the quality of explanation is a crucial determinant to developing students' understanding. Teachers speak of the failure to 'get it across' or ideas 'going down well'. Embodied in such conduit metaphors is an expectation that the normative achievement of the act of communication is success and that failure is the exception. Whereas, in contrast, as Reddy (1979) points out, the normative achievement of most communicative acts is some kind of failure and that, in contrast, it is success which is the exception. Why? From a linguistic and semiotic perspective, the central goal of science education is to help students to use the languages of science to construct and interpret meaning. For instance, from such a perspective a complex concept such as energy is represented in a variety of forms. On the one hand, it can be the symbol E, the unit of the joule, the energy levels in a graph or a mathematical equation to calculate the work done when a force moves through a distance; all of these are simply different representations of the same concept. From this perspective the issue is not one of understanding a concept that has, at the best of times, an arguable reality, but rather showing pupils how to move back and forth between the different mathematical, diagrammatic, verbal and symbolic representations of energy so that they can begin to recognise and construe the equivalencies between these forms. The meaning of the concept 'does not arise simply from each of these added to, or in parallel with, the others: it arises from the combination of each of these integrated with and multiplied by each of the others' (Lemke, 1998). Given such complexity, is it any surprise that the act of explaining science is so problematical?

THE COMPLEXITIES OF SCIENTIFIC LANGUAGE

But what is the nature of the complexities of scientific language confronting the learner? In brief these are the polysemic nature of language, the role of logical connectives, the multi-semiotic nature of its discourse and science's unfamiliar genres, aspects which are explored below.

Polysemy

Words do not simply 'carry their hearts on their sleeves'. The creation of texts is a complex creative act and the creation of meaning requires an active process of interpretation, i.e. that the act of reading is best understood as a constructive process, one in which reading depends on the background knowledge of the reader that must be deployed to evaluate critically and judge what the text in question means (de Castell *et al.*, 1986; Norris & Phillips, 1994; Olson, 1994). For words are polysemous. That this is so has been exposed by the revealing research initially conducted by Cassells & Johnstone (1980, 1985) and then repeated in similar forms by Pickersgill & Lock (1991), Farrell & Ventura (1998) and Prophet & Towse (1999). In all of this work the standard approach is to present four sentences in a multiple choice format, all containing the same word, and ask which one uses the word appropriately. The findings show that many pupils have considerable difficulty in recognising the correct scientific usage, with their understanding of words such as 'abundant', 'negligible' and 'random' described as 'weak' or 'very weak'. Montgomery (1996) argues that a consequence of language's inherent polysemy is that scientists are troubled by language. Scientists he suggests want their words to be purely technical signs with no index of meanings. But the danger of words lies in their natural ambiguity. For instance, the word 'electricity', although apparently technical, could be and is used to refer to 'electric charge', 'electric power', 'electrical voltage' or 'electrical current'. Its precise meaning can only be determined by examining the context of its use, as in the sentence 'The demand for electricity was low', where it is referring to electrical power, as opposed to the sentence 'The electricity nearly killed him', where it is referring to electrical current.

Logical Connectives and their Significance

Logical connectives are essential to the process of constructing an argument, generating the relationships between claims, warrants and data and contrasting and comparing similar and distinguishable phenomena. Problems with their comprehension and use in scientific language have been exposed by the work of Gardner (1975) and Byrne *et al.* (1994). Gardner found 75 connectives that posed difficulties to the 15 year old pupils who were the subject of his research. Yet, in science texts Wellington & Osborne (2001) have shown that they are commonly excised to *improve* readability. Granted, most teachers of science do recognise that much of the vocabulary they introduce may be unfamiliar and require careful exposition, but how many are cognisant of the converse, that many of the words they use are familiar but used with unfamiliar meanings in strange new contexts? Or that, whilst using the language of science, it is necessary to teach their students *about* that language if they are to comprehend its meaning.

Science as a Multi-semiotic Language

In the case of science, that task of teaching students about the language it uses is made more demanding by evidence that suggests that the student can be confronted with more new terms in a science lesson than a language lesson (Merzyn, 1987); that standard school science texts can contain as many as 2000 different technical terms (Brämer & Clemens, 1980), and by the fact that the student is confronted by a multi-semiotic mode of communication (Lemke, 1998). For, as Lemke argues:

> Science does not speak of the world in the language of words alone, and in many cases it simply cannot do so. The natural language of science is a synergistic integration of words, diagrams, pictures, graphs, maps, equations, tables, charts, and other forms of visual mathematical expression.

The problem for science is that natural language is very limited in its ability to describe continuous variation, shape and the interrelationships of structure, form and function. Indeed, as Lemke argues, often it *cannot* do so. For instance, consider the common standard diagram of the heart. Imagine for instance, if you will, how difficult it would be to describe this organ to another without the use of diagrammatic representation. Likewise, many other phenomena and their patterns of interaction are best described in the language of mathematics, which becomes a bridge between verbal language and the meaning scientists seek to express. So complex are some of the concepts and ideas that science wishes to capture and communicate that its language becomes dependent on a synergy of semiotic signs: symbols to represent elements, quantities and units; graphs and charts to summarise relationships, frequencies and patterns; tables to summarise numerical data; mathematics to express relationships. That these are all interdependent can be seen from a cursory examination of any contemporary scientific paper. Temporarily excising one of these components makes the process of constructing its meaning significantly harder, if not impossible. Thus, the task confronting the student is not one of learning the language of science but one of learning the *languages* of science. As Lemke elegantly describes it, it is as if:

> we said the first words of each sentence in Chinese, then the next few in Swahili, and then the last few in Hindi, and in the next sentence we started in Swahili, ... and so on.

Moreover, the language of science is exceptional in that its discourse is cumulative. This does not mean that it contains some inner hierarchy but merely that each conversation in any given scientific domain builds on ones that have gone before; science thus progresses in a fundamental way that most other disciplines do not. The consequence is that the discourse of science increasingly deviates from that of other discourses. Compare, for instance, the writings of any 19th century introduction to gravitational theory with any contemporary text on gravity with its matrix mathematics, tensor calculus and more. The two are virtually incommensurable. For the neophyte student this is an additional barrier to entry, extending the period of apprenticeship or, alternatively, restricting the field of study to an even narrower domain.

The Genres of Scientific Writing

For students, the familiar form of writing is that of the narrative. Our lives are told and represented through narratives; history is itself a narrative, albeit contested and with plural accounts; literature is the embodiment of narrative with its classic genres of romance, irony, tragedy and comedy (Frye, 1957). But what of science and, more pertinently, what of science education? Here the personal is excised and pupils are encouraged to write in the passive voice. So rather than writing 'we took the Bunsen burner and heated the copper sulphate', the standard genre of science would use the wording 'the copper sulphate was heated' resulting in the excision of any sense of an actor or the personal. Similarly, reports or explanations in science tend to remove the agents, the scene, the motives and any sense of temporality. Whereas narrative accounts are, in general, subjective accounts of experience, science, in contrast, seeks to distance itself and portray the knowledge it offers as something which is a reflection of a real world which is independent of any observer. The point at issue is not whether this is justified or whether alternative modes of communication might be more effective, rather it is that that is *how science is written*. Indeed, Martin (1998) would argue that such canonical forms of discourse enjoy hegemony within the scientific community, simply because they are functionally effective. The effect, however, is to erect a 'monolithic castle of impenetrable speech' (Montgomery, 1996) which intimidates the outsider with an ability to jam out all other forms of speech with which it comes into contact, denying challenge, argument or alternative interpretation. The consequence is that science remains distant and elevated. The pedagogical point is that such distance will *not* be reduced by an education which fails to explore such modes of writing, their rationale and justification.

BECOMING 'LITERATE' IN SCIENCE

My argument then is this, that given the complexities of scientific language, its study is not some marginal adjunct to engaging in its practice, rather it is central to the development of *any* understanding. In short, science cannot be understood without an exploration of its language. On the one hand, that does require some knowledge of its technical vocabulary. To be literate in science requires that the individual knows the concept or object represented by such words as mitosis, neutron, phenolphthalein, electron donor, gene and the myriad other words that populate the scientific universe. That much is not denied. But science is more than its vocabulary; words have value only when used as referents or to represent meanings. Knowing the vocabulary of science without understanding how it is used, or why, is akin to knowing the words of a foreign language with no understanding of its grammar or standard modalities of expression. Likewise, emphasising the role and value of empirical activity at the expense of exploring the languages of science is similar to proffering a hammer without a nail. Yes, it is essential to engage in the process of collecting empirical data to understand a significant aspect of its nature, but much of that activity is of questionable value. First, most experiments are closed, where both the problem and its method of solution have been defined by the teacher or, at the very least, constrained by the limited facilities that are available for the sets of 30 or more in which science is commonly taught. Second, both children and teacher are aware that the problem of enquiry has a well-known and consensually agreed solution (Wellington, 1981; Harris & Taylor, 1983). Thirdly, any argument that such work would develop contemporary professional skills is illusory. For the Bunsen burners, test tubes and even the IT equipment that school science deploys bear little relationship to the combinatorial chemistry, the remote sensing CCDs, the machinery of gene injection or the particle detectors of contemporary science.

In contrast, as much can be learnt about the nature and problems of empirical enquiry with a ruler and a piece of paper. Simply asking all class members to measure its length invites the question of what is its true value, why do measurements vary, how much can we trust our agreed answer, how might we record and communicate our answer and why do scientists use strange and unfamiliar forms for the manner in which they would communicate the results. The preceding example is offered not as an argument for some form of antediluvian science education but to illustrate that a major, but neglected, function of empirical enquiry should be to develop an understanding of the basis of science, its practice and values, many of which are embodied in the language it uses.

DEVELOPING SCIENTIFIC LITERACY

Such arguments for a greater focus on language carry with them a concomitant commitment to placing literacy, particularly 'scientific literacy', as one of the central aims of the science curriculum. Undoubtedly, science educators have achieved their aim of placing science at the curriculum high table. The mantra 'science for all' has an intrinsic ideological appeal that denies the current state of affairs where science is, in fact, the preserve of the few (Millar & Osborne, 1998). Yet such a victory has been largely achieved without a consideration of whether the current curriculum is an apt vehicle for this purpose or, more fundamentally, what its aims might be. For quite clearly, science education for all only has value if it offers something which is of universal value to all. Common answers to such questions are that school science attempts to develop 'scientific literacy'. Within the science education community the concept has confused and multiple meanings (Shamos, 1995; De Boer, 2000). De Boer, for instance, documents nine distinct uses of the term. Better insights are offered by Kintgen (1988), who sees four meanings associated with the term literacy or being able to describe somebody as literate. The lowest level is the ability to write and read your own name, an aspect which is clearly not the responsibility of the science teacher. The next stage is simply the recitation stage where an individual is able to recite, or read, information but has little understanding of the meaning of the words or its implications. Some of the science teaching commonly used for revision for exams often rarely transcends this level as pupils learn parrot-like answers to respond to closed and limited questions, in essence to recall the vocabulary of science without being asked to construct a meaningful sentence. Asked to justify their thinking or to relate the idea to another concept, the limitations of students' knowledge can often be cruelly exposed.

The next level of literacy is the ability to comprehend unfamiliar material, an ability which in the case of science is dependent on a good knowledge of a wide range of concepts and ideas that pervade the sciences. Many science teachers would argue that this is their major contribution to making an individual scientifically literate. My contention is not to disagree with such a position, but rather to suggest that developing an understanding of the ideas and concepts of science means that pupils need to spend 'more time interacting with ideas and less time interacting with apparatus' (Hodson, 1990). More importantly, it means that if we wish to place an emphasis on being able to read (and write) science, then it is important to develop pupils' knowledge and understanding of the standard stylistic conventions of scientific language.

How can this be done? First, without this case for the importance of language in science education being acknowledged, all else is in vain. Freeing science classrooms from their obsession with content knowledge and its recall, an aspect which is reflected by the predominance of closed questioning and a discourse that takes the form of a teacher-initiated question, a student response and, then, evaluative comment (Edwards & Mercer, 1987; Lemke, 1990), is not a minor task. At one level it requires a cultural shift to recognising that the function of science education is not the pre-professional preparation of an elite that will become our future scientists and technologists. Rather, it is a preparation for citizenship and an exploration of the cultural hegemony science enjoys in Western societies. Granted, such a science education does require some conventional study of natural phenomena and the major explanatory themes offered by science. However, a concomitant commitment is recognition that such an education requires an assessment of the qualities necessary for citizenship in a scientific society, the ability to recognise specific aspects of its practice, to distinguish an observation from a hypothesis, a prediction from a conclusion. In short, to recognise the major landmarks that underpin any scientific narrative. Such features are, however, only the foundations required for the critical and evaluative interpretations of reports about science which are, for the majority, media reports of science. And it is this skill which research shows contemporary science education is substantively failing to achieve (Norris & Phillips, 1994; Zimmerman *et al.*, 1999). For it is this form of literacy, the evaluative in which the reader is expected to analyse and critique what they read and interpret meaning, which is the highest and most demanding. Generally, it requires a substantive knowledge of the domain and the forms by which it is represented and communicated. Several authors have argued that this is simply an aspirational myth (Shamos, 1995) and that even scientists are illiterate outside their own specialist domain (Greene, 1997). My view would be that to portray 'scientific literacy' as a bivalent quality which an individual either has or does not have is mistaken. Rather 'scientific literacy' exists on a continuum between being totally illiterate (and totally dependent on others) to acknowledged expertise (and minimal intellectual dependence). Knowing and understanding *both* some of the content *and* the appropriate use of language of science is an essential component on the path towards such scientific literacy.

At one level, more effective teaching of language within the science classroom requires the recognition and development of practices that support and scaffold the development of reading, writing and the exploration of meaning (Wellington & Osborne, 2001). For reading, valuable work has been undertaken by Davies & Greene (1984), and for writing, the more recent work of Wray & Lewis (1997) provides seminal insights into ways in which the student can be apprenticed into the standard genres of scientific writing. However, the area which is neglected is research which has investigated how to explore and develop students understanding of *scientific reasoning*. At the tertiary level, significant attempts have been offered by Giere (1991) and Garratt *et al.* (1999). At the secondary level, the work of Watson & Wood-Robinson (1998) and Goldworthy *et al.* (1999, 2000) offers a range of structured means for exploring the evaluation of evidence. Our current work on evaluating the quality of argument (Osborne *et al.*, 2001) in school science seeks, likewise, to develop materials that can scaffold the examination of argument in school science. A significant feature of this work is the presentation of plural alternatives and evidence which can form the substantive data of the argument. There is also a requirement for small group discussion, to talk the language of science and occupy the evidence–evalu-

Competing theories

Theory 1: **Light rays travel from our eyes onto the objects and enable us to see them.**
Theory 2: **Light rays are produced by a source of light and reflect off objects into our eyes so we can see them.**

The following evidence is available. Discuss each piece of evidence and decide which idea each piece of evidence supports.

a. Light travels in straight lines
b. We can still see at night when there is no sun
c. Sunglasses are worn to protect our eyes
d. If there is no light we cannot see a thing
e. We 'stare at' people, 'look daggers' and 'catch people's eye'
f. You have to look at something to see it.

FIG. 2. Example of materials used to support the exploration of scientific argument in the EQuAS project.

ation space, and explore the interaction between theory and evidence (see Fig. 2). At this stage of our work a challenge posed by such work for science teachers is the use of small group discussion and the evaluation of their learning.

At another level, it requires recognition that the implemented curriculum is as much a product of the means by which it is assessed as the intentions of well-meaning curriculum documents. Raising the attention given to the teaching and exploration of language requires, at least for school science, new forms of assessment that necessitate the reading and writing of science and the analysis of scientific argument. It is promising to note, then, that some attention is now been given to broadening the base of the contemporary science curriculum and the manner in which it is examined (Hollins, 2001).

Space does not permit further discussion of such important initiatives. However, for too long any focus on such literary practices have been an additional, extraneous practice of science teaching, a 'bolt-on' element, which like all such aspects has a nasty habit of dropping off under the pressures and exigencies of limited time. The argument here has been that literacy is not an additional element but an essential constitutive practice of science whose study is as vital to science education as sails are to ships, bricks are to houses or engines to cars. Improving the quality of science education, both in terms of the experience it offers to its students and its cognitive and affective outcomes, requires the restoration of language and literacy to the central position it occupies in its practice; nothing less will suffice.

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