LANGUAGE AND LITERACY IN SCIENCE EDUCATION

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Foreword

Reading, writing, hearing, and especially talking science are a large part of what professional scientists do. Along with some time spent in practical work, they are *most* of what science teachers and pupils do. In this very practical book, Jerry Wellington and Jonathan Osborne do much more than summarize research which shows how very much language, in all its forms, matters to science education. They also show teachers what can be done to make learning science through language both more effective and more enjoyable.

Intelligently, this is not a book just about language and science teaching. It recognizes that in science we teach and learn by *combining* language with pictures, diagrams, charts, tables, graphs and other specialized scientific and mathematical symbols. It places teachers' and students' use of scientific and everyday language in the real contexts of classroom dialogues, note-taking, groupwork, practical work, textbook reading, report writing and examinations. It is not simply *language* that matters in science education, but what we *do* with language.

In its nine chapters, *Language and Literacy in Science Education* examines many aspects of the two principal uses of language in science education: (a) how we use language as teachers and pupils to communicate and to structure learning; and (b) how we learn to use language as scientists themselves do – to name, describe, record, compare, explain, analyse, design, evaluate, and theorize how the natural world appears to us. What twenty years of research on science classrooms has shown is that (a) and (b) are inextricably entangled with one another.

The organization of classroom activity *for science* has to take into account the nature of scientific concepts, scientific language, scientific reasoning and scientific values. It is not enough to ask students to read the textbook: you have more specifically to structure the reading task so that they will ask the kinds of silent questions a scientist would ask. It is not enough to assign a report to be written: you have to teach them what questions that report should answer, how the answers should be logically connected to each other and how each answer and each connection should be put into the right kind of words, sentences and paragraphs. These are two of the more formal language tasks of the science curriculum, but even in the more informal give-and-take of whole-class or small-group discussion, there are also more scientific ways of talking, which support more scientific ways of reasoning. All teachers look and hope for more scientific forms of expression and reasoning from their pupils, but few have been taught specific techniques for supporting students' use of scientific language. This book is full of them.

Scientific language is not just specialist vocabulary, as this book makes very clear. In fact it is possible to discuss a topic very scientifically without heavy use of technical vocabulary, *if* you can use the right kind of language to scaffold deductive and inductive reasoning, formulate hypotheses, make generalizations, identify exceptions, connect evidence to theses, classify, relate, organize, plan and persuade. Much of this language is not entirely unique to science, but it is adapted to more specialized purposes in science, and it represents that specific contribution of science teaching to pupils' general intellectual development which is most likely to carry over into other subjects and into the rest of their lives. The forms of scientific language scaffold, support and channel our thinking, reasoning, insight and even our creative imagination.

Too many pupils care less and less for science as a school subject the more of it they've taken. Too often, with the best intentions, our teaching of science frustrates students who know we expect them to understand, but who also know that they don't (even when they seem to).

Many factors are at work here, but an important one is the extent to which pupils learn to feel comfortable with the style of scientific reasoning and analysis and with the forms of language that support it. We can see their faces light up when we tell a story in science class; they are used to the language forms of stories, they know how to learn from narratives. Many of the results of scientific research can be framed as stories, but little of the processes of reasoning, analysis and deduction that led to those results. If we want to erase the looks of disappointment and anxiety that greet the end of the story and our return to more scientific forms of discourse, we have to work harder to make these strange forms more familiar. We have to unpack and display the organization and logic of scientific ways of using language. This book shows us how to get started.

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In writing this book we have drawn upon a wide range of sources on language and literacy in science education. Our aim has been to consider as many articles, books and other sources as possible and to attempt to bring them together and highlight their practical implications within the covers of this book. We would like particularly to acknowledge the following books, which we feel have been a major influence on ourselves and many other people in this area of science education. They are given in chronological order:

Douglas Barnes (1969) *Language, the Learner and the School*. Harmondsworth: Penguin.

Clive Carré (1981) *Language Teaching and Learning: Science*. London: Ward Lock.

Florence Davies and Terry Greene (1984) *Reading for Learning in the Sciences*. Edinburgh: Oliver and Boyd.

Lesley Bulman (1985) *Teaching Language and Study Skills in Secondary Science*. London: Heinemann.

Clive Sutton (1992) *Words, Science and Learning*. Buckingham: Open University Press.

M. A. K. Halliday and J. R. Martin (1993) *Writing Science: Literacy and Discursive Power*. London: Falmer Press.

David Wray and Maureen Lewis (1997) *Extending Literacy: Children Reading and Writing Non-fiction*. London: Routledge.

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Jerry Wellington and Jonathan Osborne

1 Introduction: the importance of language in science education

Why have we written this book?

This book has emerged from a belief that language in science matters. We believe that there is a body of disparate research of the past 30 years that shows that one of the major difficulties in learning science is learning the language of science. Tragically, this is not a message that has reached the science teaching profession, for experience would suggest that science teachers often consider it to be of marginal relevance to the learning of science. Our view, therefore, is that paying more attention to language is one of the most important acts that can be done to improve the quality of science education, and this book is an attempt to reach the parts that research may have failed to reach.

Apart from one book published by Lesley Bulman (1985) and another important volume written by Davies and Greene (1984), both now out of print, there is no single volume which gathers together the important work that has been done in this area. Our intention, therefore, in this book has been to attempt to collate and collect all of the major pieces of work and ideas that we believe are important to the practice of science teaching in one volume. Inevitably, space limitations have meant that we are unable to present some of the arguments and data from the original research in the detail we would have liked to. However, we believe we have distilled the key issues and practical guidelines about language and literacy in science education from a range of sources, including our own work, in a form which is, we hope, both easily understood and practically orientated. Those who wish to explore the original work in more detail will find references to the main work conducted in this field and are encouraged to pursue it further, as much of it makes fascinating reading and an even stronger case for the significance of language in learning science.

Three basic starting points

We base this book on three premises:

1 Learning the language of science is a major part (if not *the* major part) of science education. Every science lesson is a language lesson.
2 Language is a major barrier (if not *the* major barrier) to most pupils in learning science.
3 There are many practical strategies which can help to overcome these barriers.

We begin the book by asking what the major language barriers are – what can research tell us in this area and how can they be 'diagnosed'? We then go on, in later chapters, to examine practical ways of overcoming the barriers to retaining, understanding, reading, speaking and writing the language of science.

The aims of this book

The aims of the book are:

- To raise awareness of the different types of language in science and the demands they make on young learners, e.g. which words cause most difficulty; what language demands does 'scientific investigation' and practical work more generally pose; what language barriers are presented by examination papers; how readable are published schemes, past and present?
- To consider pupil–teacher dialogues in the classroom, we examine some of the interesting 'games' between teachers and pupils, often dependent on unwritten 'ground rules'. These dialogues also depend on some high-level teaching skills, such as the art of questioning and the knack of 'explaining'.
- To examine the nature of reading in science education and how it might be improved.
- To consider the importance of talking, discussion and argument in science classes and practical ways of developing them.
- To discuss pupils' writing in science and how this relates to learning science.
- To look at existing practical teaching ideas, resources and strategies for lowering some of the barriers, e.g. wordbanks and glossaries, publishers' resources, classroom tactics.
- To present and consider a range of activities, ideas or resources which can be used in the classroom, e.g. card games, DARTs; newspaper reading, IT resources from CD-ROM or the Internet.
- To discuss how these ideas can contribute to literacy development in general and more specifically to the public understanding of science and scientific literacy.
- To present ideas for further reading and teachers' own classroom based research which can be followed up by teachers and other readers.

Why is language important in science education?

The focus of secondary education has largely been on science as a practical subject, often quite rightly, for science is partly an empirical subject. But for many pupils the greatest obstacle in learning science – and also the most important achievement – is to learn its language. One of the important features of science is the richness of the words and terms it uses.

Almost all teaching and learning take place using the medium of language, verbal and non-verbal. This involves some fairly complex processes and interactions, many of which (as we see in Chapter 3) depend on tacit ideas, implicit ground rules and traditional beliefs about what is expected in classrooms. Yet the dominant metaphor for teaching has now become 'delivery' – what we call the Postman Pat model of education. The word deliver now abounds in mission statements, curriculum policies, staff meetings and even ASE conference programmes. If we could remove one word from the English language this would be our first choice. We recently read a strategic plan for a university which talks of 'delivering learning' as if it was some sort of package or commodity which is passed on to the student, stored in a kind of pigeon hole and later redelivered to a higher authority when assessment or examinations come around. We hope to show in this book that learning and teaching in science classrooms is (and always has been) a bit more complex than the delivery model, mainly because human beings rather than post office sorting machines are involved. The message of the past 20 years of research in science education has been that learners are much more than post boxes.

The policy background

The debate about language in science education goes back a long way. For brevity, we start in the 1970s. Two of the fashionable authors of that era (one named, ironically, Postman) wrote:

> Almost all of what we customarily call 'knowledge' is language, which means that the key to understanding a subject is to understand its language. 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. Unless and until new words were invented. Then we would have a 'new' biology! What is history other than words? Or astronomy? Or physics? If you do not know the meanings of history words or astronomy words you do not know history or astronomy. 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.
>
> (Postman and Weingartner 1971)

Four years later the Bullock Report was published, which advocated that all teachers should see themselves as teachers of language. One specific suggestion was that science teachers should examine the dialogues which go on in the classroom so that they can become more skilful in 'orchestrating it':

> We need to begin by examining the nature of the language experience in the dialogue between teacher and class . . . By its very nature a lesson is a verbal encounter through which the teacher draws information from the class, elaborates and generalises it, and produces a synthesis. His skill is in selecting, prompting, improving, and generally orchestrating the exchange.
>
> (Bullock 1975: 141)

More recently, there has been a strong, centrally driven, curricular justification for an increased emphasis on language in science teaching. The *Science in the National Curriculum* document (DfEE/Welsh Office 1995) included a 'Use of Language' section in its Common Requirements for all key stages: 'Pupils should be taught to express themselves clearly in both speech and writing and to develop their reading skills. They should be taught to use grammatically correct sentences and to spell and punctuate in order to communicate effectively.' This statement was interpreted by the School Curriculum and Assessment Authority (SCAA, which then became QCA) as a call for 'clarity and correctness' in speaking and writing. The Programmes of Study also include a section on communication which states that pupils should be taught to: 'use appropriate scientific vocabulary to describe and explain the behaviour of living things, materials, and processes.'

The message was reinforced for the new century by the National Curriculum documents which took effect in 2000. All documents from QCA include a section on *Use of language across the curriculum*. This page makes statements on reading, writing, speaking and listening:

1 Pupils should be taught in all subjects to express themselves correctly and appropriately and to read accurately and with understanding.

Writing

2 In writing, pupils should be taught to use correct spelling and punctuation and follow grammatical conventions. They should also be taught to organize their writing in logical and coherent forms.

Speaking

3 In speaking, pupils should be taught to use language precisely and cogently.

Listening

4 Pupils should be taught to listen to others, and to respond and build on their ideas and views constructively.

Reading

5 In reading, pupils should be taught strategies to help them read with understanding, to locate and use information, to follow a process or

argument and summarise, and to synthesise and adapt what they learn from their reading.

6 Pupils should be taught the technical and specialist vocabulary of subjects and how to use and spell these words. They should also be taught to use the patterns of language vital to understanding and expression in different subjects. These include the construction of sentences, paragraphs and texts that are often used in a subject (for example, language to express causality, chronology, logic, exploration, hypothesis, comparison, and how to ask questions and develop arguments).

(The National Curriculum for England, QCA, London, 1999: 69)

These 'general teaching requirements', incidentally, pose some fairly tough demands on teachers – especially the last sentence in the extract above, which we return to in a later chapter.

Finally, there is a strong justification for a focus on language if formal science education is to be a major contributor to citizenship and the public understanding of science. Pupils should learn the language of science so that they can read critically and actively and develop an interest in reading about science; and develop competence in sceptically scrutinizing claims and arguments made in the press and on television based on 'scientific research' or 'scientific evidence', e.g. in the long-running BSE debate or the discussion on GM foods. This means, for instance, that they should be able to distinguish a cause from a claim, an assertion from an argument, a hypothesis from a conclusion and evidence from speculation.

Treating language with care

One of our key themes in this book is that science teachers are (among other things) *language* teachers. This requires a range of strategies and skills, some of which are at a high level. In later chapters we discuss, and present ideas on, the many skills which a focus on language in science education demands. Learning science is, in many ways, like learning a new language. In some ways it presents more difficulty in that many of the hard, conceptual words of science – such as energy, work, power – have a precise meaning in science and sometimes an exact definition, but a very different meaning in everyday life. Science education thus involves dealing with familiar words, like energy, and giving them new meanings in new contexts. Equally, many of the 'naming' words of our lives have been commandeered by science. Consider: element, conductor, cell, field, circuit, compound. This is made worse because many of the terms of science are metaphors: for example, a field in science is not really a field. Science education also involves introducing *new* words – sometimes in familiar contexts (e.g. tibia, fibula) but at other times in unfamiliar contexts (e.g. allele, enzyme, longitudinal).

Another category of language which science teachers (and many other teachers) use has been christened the 'language of secondary education' (see Chapter 3). The list includes modify, compare, evaluate, hypothesize, infer, recapitulate . . . and so on. These are words used by teachers and exam papers but rarely heard in playgrounds, in pubs or at football matches.

What should science teachers do about their specialist language and the language of secondary education?

Our general approach in this book is that we should all treat language with care, to be aware of its difficulties and to bear in mind that although pupils can and do use scientific terms in speech and writing this does not imply that they understand them (this is equally true of journalists, other writers and radio or TV pundits of course). But this does not imply that we should 'skirt round it' or try to avoid the language of science and constantly translate it into the 'vernacular'. This approach gained some credence in the 1980s and 1990s when (for example) Maskill (1988) urged teachers to use 'common' words where possible: 'Don't use one (uncommon) word when ten other more familiar will do. The ideas of science are very difficult for the majority of pupils and so language must be kept as simple as possible' (Maskill 1988: 490). (A similar trend occurred in the drive to make textbooks more readable by, for example, removing 'logical connectives' from pupils' books and subsequently examination papers – discussed in Chapter 4.)

We have some sympathy with Maskill's and others' sentiments here – the ideas of science are often difficult. But learning to use the language of science is fundamental to learning science. As Vygotsky (1962) pointed out, when a child uses words he or she is helped to develop concepts. Language development and conceptual development are inextricably linked. Thought requires language, language requires thought. Viewed from a negative angle, 'difficulty with language causes difficulty with reasoning' (Byrne *et al.* 1994).

In the 1970s, one of the key researchers in this area pointed out that 'It was unlikely that a teacher would enter a classroom with the deliberate intention of teaching the meaning of a word' (Gardner 1974). This is still too often the case. Our argument in this book is that we can only learn and teach a new language by providing opportunities to practise its use. This book sets out to show how such opportunities for practice can be provided and enhanced.

Communicating science: more than just words

> What use is a book without words and pictures?
>
> (Lewis Caroll, *Alice in Wonderland*)

Finally, we all need to remind ourselves that there is far more to science communication than verbal language, i.e. the spoken and written word. Words are important but in science more than any other subject we rely on a combination and interaction of words, pictures, diagrams, images, animations, graphs, equations, tables and charts (Lemke 1998; Jones 2000). They all convey meaning in different ways – they all have their own importance and their own limitations. For example, the old saying that 'a picture is worth a thousand words' is probably true, but it does not go far enough. There are certain meanings we wish to convey in science that cannot possibly be put across in words alone. Messages and meanings in charts and graphs, for example, can never be replaced by the written word, whether we use one thousand or two. The smells of science (which adults remember most vividly of all from their science lessons) or the touch and feel of practical work cannot be put into words. Gestures and other body language can convey scientific ideas more effectively and memorably than chalk and talk, or a passage in a textbook.

In the jargon of linguists, there is a range of *semiotic modes* available to the science teacher (semiotics can be defined as the study of how we make meaning using words, images, symbols, actions and other modes of communication). The onus on the good teacher is to employ these modes appropriately, i.e. in the right place at the right time for the right reasons. For example, chalk and talk might be fine for teaching some ideas, but others, e.g. change of state, may require animation (perhaps with multimedia or simpler teaching aids like marbles or ball bearings). The movement of plates in plate tectonics can be described in words but might be better conveyed using gestures and hand movements. Equations and mathematical symbols can sum up for some pupils in a nutshell some difficult ideas which are very lengthy in words (although symbols may not suit every learner). Ideas such as rate of change, proportionality and decay might best be shown on a graph. Cyclical processes, e.g. the carbon cycle, can best be shown using a diagram with arrows, while sequences such as the manufacture of a chemical can be seen visually with a flowchart.

We all know this and in some ways it is no more than common sense. But the art of good communication in science teaching would seem to involve at least three skills, some of which can be deliberately trained for and developed or coached, while others just seem to be part of the 'tacit', hidden knowledge and ability of the 'born teacher'. These are:

1. The recognition that teaching does involve a range of modes of communication. In science, we have at our disposal:
   - the spoken and written word;
   - visual representation;
   - images, diagrams, tables, charts, models and graphs;
   - movement and animation of physical models, e.g. beach ball for the Sun, a pea for the Earth, or using multimedia, gesture or other body language;
   - practical work, with its feel, touch, smell and, of course, sounds;
   - mathematical symbols, either as shorthand or in the form of equations to convey a connection.

   Teachers need to be aware of this wide range of modes and of how to use them in developing pupils' knowledge and understanding in science.
2. The awareness of these different modes and the recognition that different modes suit different learners, i.e. learning styles vary. Some modes work best for some learners – other ways of conveying meaning work better with others.

3 The ability (which is often described as tacit or intuitive) to switch from one mode to another when teaching. If one way is not working then good teachers switch to another way according to the teacher's awareness of, and alertness to, the class. Even within a mode, e.g. the spoken word, one line of explanation or one analogy may not be working with a group of pupils. The teacher's knack is to move to a different approach within that mode, or even a new mode completely, e.g. to use a physical model instead of talk or chalk. Each mode has its value – and its limitations.

In summary, communicating in science teaching presents both a challenge and an opportunity. Science education involves a range of ways of communicating (visual, verbal, graphical, symbolic, tactile) which can be exploited to engage with different learning styles or abilities and to provide a variety of teaching approaches.