CRITICAL PERSPECTIVES ON LITERACY AND EDUCATION

Writing Science

Literacy and Discursive Power

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Series Editor's Introduction

In *Language as Social Semiotic* (1978), Michael Halliday maps the possibilities of a 'social-functional' approach to linguistics. There he distinguishes 'intra-organistic' from 'inter-organistic' explanations of language, noting the contemporary tendency to explain language use by reference to the 'intra-organistic', that is, by reference to internal, psychological states. This critique applies most obviously to psycholinguistic and cognitive developmental models of 'language acquisition', which have been central in the shaping of literacy in Western schools. But, Halliday indicates, it also applies to those socio-linguistic and ethnographic models that pay homage to 'social context', but tend to explain away the constitutive institutional and ideological relations of text and discourse in terms of individuals' knowledges, intents, states of mind, competences, and so forth. In its stead, Halliday has developed a theory of language as social semiotic performance. The traditions that systemic linguistics draws upon, from Hjelmslev and Malinowski to Durkheim and Voloshinov, are used to build a recognition of the primacy of the social.

Writing Science shows how modern science is, first and foremost, a discourse technology. Here Halliday and James R.Martin show scientific discourse at work in a range of historical, contemporary, and cross-cultural sites: from the works of nineteenth century science, to other cultures' textual representations of the natural world, from school students' writings on scientific knowledge and procedures, to the construction of a 'Secret English' of science in secondary school textbooks and classroom talk. Throughout these essays, science is not taken as a canon of 'great' ideas and truths, nor as a corpus of universal procedures or methods, or, even more mystically, as the product of 'genius', specific mental dispositions and attitudes. Rather, science is conceived of as inter-organistic practice, a linguistic/semiotic practice which has evolved functionally to do specialized kinds of theoretical and practical work in social institutions. Accordingly, Halliday and Martin argue that scientific texts needn't be 'alienating' and 'anti-democratic', but can be deconstructed and made accessible, as part of a broad agenda to linguistically 'construe a world which is recognizable to all those who live in it'. Running across these essays is a commitment not just to remaking science as a humane endeavour, but also to developing new analytic perspectives for critiquing science.

As Derrida (1974) and Lyotard (1982) would insist, to speak of 'science' and a 'science of writing' is to presuppose and build a possible world where both writing and science have been assigned special significance. It should not be surprising, then, that current debates over postmodernity, technology, and attendant shifts in political economy and culture turn on the place of the texts and institutions of science. What counts as 'science' in the period since World War II has been focal in the development of Western nation states, to the point where historical 'winners' and 'losers' in economic, strategic and geopolitical realms are assessed in terms of technological and scientific prowess. The yoking together of scientific work with the imperatives of capital and government had, of course, ample precedents in the late nineteenth century and early twentieth century UK, USA and Germany. But post-war technocratic society had its basis in the symbiotic relationships forged between governments, corporations and research science during World War II (De Landa, 1991). Then, applied approaches to physics, mathematics and statistics, electronics and computing, communications and systems theories, engineering and chemistry emerged—advances which would reshape the character of everyday life and mass consumer culture, research and academic institutions, and indeed, the international distribution of wealth and power. Long before McLuhan and colleagues talked of a transnational culture of electronic signs and semiotic exchange—the necessary material conditions were set in the linking of academic scientific research, first with the state-funded military industrial complexes, and later with the interests of corporate capital. The heady effects of this mix remain, as the Gulf War, economic globalisation and current ethical and legal debates over AIDS research, the Human Genome Project and reproductive technologies, global warming and environmental desecration remind us. What has come to count as science in technocratic culture is the applied, the corporate and the profitable.

In this period of flux and transition, disciplinary and institutional boundaries between science and humanities, between the 'hard' natural sciences and 'soft' human sciences, between the public discourses of science and domains of folk wisdom have become the focus of unprecedented scrutiny. This could be attributed to 'paradigm shift', as attested to by the scepticism within scientific communities towards classical mythologies of scientific objectivity, method and discovery, and the increasing attention paid to the significance of accident, intuition, ignorance and, indeed, chaos in inquiry. But driving the debate has been the sustained sociological and philosophical critique of scientific work, knowledge and power. Social sciences have made the cultural and sociological workings of science an object of study: in the poststructuralist critique of sciences by Foucault and Lyotard; the critique of the 'science of writing' by Derrida; feminist analyses of patriarchy and science by Harding and Haraway; and critical sociologies and ethnohistories of scientific inquiry by Hacking, Rose, Gould, Woolgar and others (for an introduction and bibliography, see Darnovsky, Epstein & Wilson, 1991).

What is at stake is far more than disciplinary and academic turf. In the midst of tenacious political and economic legitimation crises, the whole game may be up for grabs. In a global economy where reliance on technological 'growth' and 'progress' is greater than ever—the power of scientific discourse (and its kin, pseudo-science and pop science) is arguably greater than ever before. The very dependency on corporate science and technological expansion as means for the expansion of state power and legitimacy have translated the crises of economies and cultures into the crises of sciences.

The 'time lag' between such debates and a remaking of science education is not surprising, given the persistent problems of reform of school systems and curriculum largely built by industrial-era design and edict. In the USA and Canada, the UK and Australia, the post-war human capital model of education has proven resilient and recyclable, despite little evidence that it works (Lingard, Porter & Knight, 1992). Faced with service and information-driven economies, finite resources, and shifting patterns and sectors of employment—educational policies and practices in these countries have been driven by the economic promises affiliated with the increased educational 'output' of scientific expertise. Yet this continued mystique about the achievement and value of scientific knowledge stands in contrast to the relative underdevelopment of approaches to science education. Educational research and teacher education have made halting moves from fact-transmission pedagogies to progressivist models which stress exploration and construction of scientific knowledge. Yet apart from Jay Lemke's *Talking Science* (1990), a theoretical and educational companion to *Writing Science*, the reworking of scientific education in terms of language, text and discourse has not received widespread attention from science educators, curriculum developers or teacher educators.

A socially-based linguistic analysis of the texts and discourses of scientific work, then, is an important political and pedagogical move. For many readers, these essays will be a first introduction to systemic functional linguistics at work. In Halliday's model, lexicogrammatical choice can be traced systematically to social/ideological function. This puts it at odds with mainstream linguistic analyses, which do not effectively unknot the reflexivity between the social and the semiotic, between context of situation and lexicogrammar.

Beginning from an introduction to key concepts of systemic linguistics, Halliday and Martin here move on to explore the historical relationships between science, language and literacy. There is vigorous academic dispute over the connections between scientific institutions and technologies of inscription, but historians and anthropologists from Mumford to Goody insist that writing is the enabling technology for 'doing' modern science. As many have pointed out, the writing of history and the framing of disciplinary knowledges were closely allied with the formalization of the Greek alphabetic system. Halliday and Martin argue that the languages and discourses of science indeed have characteristic features that have evolved to do various forms of cognitive and semiotic work which the 'common-sense' language of everyday life cannot: including, for instance, the representation of technicality and abstraction. Hence, the answer of many educational and public approaches to science—to do away with 'jargon' and return to 'plain English'—is a naive educational solution, doing justice neither to scientific work and knowledge, nor to those students who require direct access to the registers of disciplinary knowledge in order to progress through academic systems.

Writing Science tables a range of questions which have long been at the periphery of educational and curriculum debate. Partly because higher achievement in the traditional natural sciences has been an exclusive domain of upper and middle class male elite—little systematic effort has been devoted to exploring scientific literacy and an inclusive pedagogy that better enfranchises women, aboriginal peoples, ethnic minorities and working class children. Part II here moves towards a pedagogy which centres on how scientific language and texts work. This approach will be of value for those teaching science at all levels, for those introducing first and second language learners to the 'special purposes' of scientific writing. The linguistic analysis of what Halliday, Martin and colleagues call the 'Secret English' of school science is the basis for an approach to critical literacy which differs significantly from the emphasis on personal voice, identity and expression prevalent in UK and US. The emphasis here is on self-conscious control over text types and their special linguistic features. Halliday and Martin thus see critical science and critical literacy as commensurate and worthy educational aims, part of a move towards 'more democratic forms of discourse'.

There might indeed be scientific 'facts', constructed and contestable but verifiable truth claims about the natural and social worlds. But, as Lyotard (1984) has pointed out, what is crucial is how these are strung together into a narrative syntax, how they are chained together into sequences of agents and causes, relations and consequences. *Writing Science* indicates how the work of science is necessarily grammatical: naming, constructing and positioning the social and natural worlds, and doing so in a way which builds social relationships of power and knowledge between writers and readers. If we view science as discourse performance, not as a mental accomplishment but as social and textual practice—then what is entailed is nothing less than a political economy of discourse. How science is written and read, spoken and heard is necessarily tied up with questions of access, education and critical literacy.

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Townsville, Australia
October, 1992

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Introduction: The Discursive Technology of Science

Chapter 1

General Orientation

Adults may choose to deny it, but children in school know very well that there is a 'language of science'. They may not be able to say how they know it; but when they are faced with a wording such as:

> One model said that when a substance dissolves, the attraction between its particles becomes weaker. (Junior Secondary Science Project, 1968, pp. 32–33)

they have no trouble in recognizing it as the language of a chemistry book. And they tend to feel rather put off by it, especially when they find themselves challenged with a question like this one. 'What might happen to the forces of attraction which hold the particles of potassium nitrate together' (ibid.)

If children do get put off by this, we respond, as seems natural to us, by giving their feeling a name. We call it 'alienation'. We have now labelled the condition; we think that in labelling it we have diagnosed it, and that in diagnosing it we are half way towards curing it. In reality, of course, we have only made the condition worse. Nothing could be more alienating than to learn that you are suffering from alienation. But in responding in this way we have helped to demonstrate how scientific discourse works.

It is not only schoolchildren who have felt alienated by the discourse of science. Within a century of the so-called 'scientific revolution' in Europe, people were feeling disturbed by the picture that science presented, of a universe regulated by automatic physical laws and of a vast gulf between humanity and the rest of nature. Prigogine and Stengers, in their remarkable book *Order out of Chaos*, show how this feeling arose; and they point to the disturbing paradox between the humanist origins of natural science and its contemporary image as something unnatural and dehumanizing:

> Science initiated a successful dialogue with nature. On the other hand, the first outcome of this dialogue was the discovery of a silent world. This is the paradox of classical science. It revealed to men a dead, passive nature, a nature that behaves as an automaton which, once programmed, continues to follow the rules inscribed in the program. In this sense the dialogue with nature isolated man from nature instead of bringing him closer to it. A

> triumph of human reason turned into a sad truth. It seemed that science debased everything it touched. (Prigogine and Stengers, 1984, p. 6)

To understand this paradox, we have to take account of the kind of language in which science is construed. In his revealing account of science education, based on a study he carried out in New York secondary schools, Jay Lemke put it this way:

> How does science teaching alienate so many students from science? How does it happen that so many students come away from their contact with science in school feeling that science is not for them, that it is too impersonal and inhuman for their tastes, or that they simply 'don't have a head for science'? One way this happens, I believe, is through the way we talk science. The language of classroom science sets up a pervasive and false opposition between a world of objective, authoritative, impersonal, humourless scientific fact and the ordinary, personal world of human uncertainties, judgments, values, and interests. (Lemke, 1990a, pp. 129–30)

But the language of classroom science is simply the language of science adapted to the classroom. It fails to overcome the problem; but it did not create it in the first place. The issue is that of the discourse of science itself.

Where children are most likely to be put off is in the early years of secondary school, when they first come face to face with the language of their 'subjects'—the disciplines. Here they meet with unfamiliar forms of discourse; and since these often contain numbers of technical terms, when we first reflect on scientific language we usually think of these as the main, perhaps the only, source of the difficulty. There are a lot of technical terms, of course, and they may be quite hard to master if they are not presented systematically. But children are not, on the whole, bothered by technical terms—they often rather enjoy them; and in any case textbook writers are aware of this difficulty and usually manage to avoid introducing too many of them at once. It is not difficult, however, to find passages of wording without many technical terms which are still very clear instances of scientific writing; for example

> One property at least (the colour) of the substance produced is different from the substances that were mixed, and so it is fairly certain that it is a **new substance**. (Junior Secondary Science Project, 1968, p. 43)

Compare the example quoted in chapter 2 below:

> Your completed table should help you to see what happens to the risk of getting lung cancer as smoking increases. (Intermediate Science Curriculum Study, 1976, p. 59)

And this is not simply a feature of the language of science textbooks; the following extract from the *Scientific American* contains hardly any technical terms:

> Our work on crack growth in other solids leads us to believe that the

general conclusions developed for silica can explain the strength behaviour of a wide range of brittle materials. The actual crack tip reactions appear to vary from material to material and the chemistry of each solid must be considered on a case-by-case basis. (Michalske and Bunker, 1987, p. 81)

Of course, technical terms are an essential part of scientific language; it would be impossible to create a discourse of organized knowledge without them. But they are not the whole story. The distinctive quality of scientific language lies in the lexicogrammar (the 'wording') as a whole, and any response it engenders in the reader is a response to the total patterns of the discourse.

Naturally it would engender no response at all unless it was a variety of the parent language. Scientific English may be distinctive, but it is still a kind of English; likewise scientific Chinese is a kind of Chinese. If you feel alienated by scientific English this is because you are reacting to it as a form of a language you already know very well, perhaps as your mother tongue. (If on the other hand you are confronting scientific English directly as a second language, you may find it extraordinarily difficult, especially if it is your first encounter with a language of science; but that is very different from being alienated by it.) It is English with special probabilities attached: a form of English in which certain words, and more significantly certain grammatical constructions, stand out as more highly favoured, while others correspondingly recede and become less highly favoured, than in other varieties of the language. This is not to imply that there is one uniform version of it, any more than when we talk of British English or Australian English we are implying that there is one uniform version of each of these dialects. Any variety of a language, whether functional or dialectal, occupies an extended space, a region whose boundaries are fuzzy and within which there can be considerable internal variation. But it can be defined, and recognized, by certain syndromes, patterns of co-occurrence among features at one or another linguistic level—typically, features of the expression in the case of a dialect, features of the content in the case of a functional variety or 'register'. Such syndromes are what make it plausible to talk of 'the language of science'.

Given the view of language that prevails in western thought, it is natural to think of the language of science as a tool, an instrument for expressing our ideas about the nature of physical and biological processes. But this is a rather impoverished view of language, which distorts the relationship between language and other phenomena. The early humanists, founders of modern science in the West, paid more serious attention to language in their endeavours. In part, this was forced upon them because they were no longer using the language that had served their predecessors, Latin, and instead faced the job of developing their various emerging 'national' languages into resources for construing knowledge. But their concern with language went deeper than that. On the one hand they were reacting against what they saw as (in our jargon of today) a logocentric tendency in medieval thought; the best-known articulation of this attitude is Bacon's 'idols of the marketplace' *(idola fori)*, one of the four *idola* or false conceptions which he felt distorted scientific thinking. The *idola fori* result, in Dijksterhuis' words,

from the thoughtless use of language, from the delusion that there must correspond to all names actually existing things, and from the confusion of the literal and the figurative meaning of a word. (Dijksterhuis, 1961, p. 398)

The 'delusion' referred to here had already been flagged by William of Occam, whose often quoted stricture on unnecessary entities was in fact a warning against reifying theoretical concepts such as 'motion'; the perception that lay behind this suspicion of language was later codified in the nominalist philosophy of John Locke, summed up by David Oldroyd as follows:

> The important point, of course, is that the new philosophy claimed that new knowledge was to be obtained by experimentation, not by analysis of language or by establishing the correct definitions of things. If you wanted to know more about the properties of gold than anyone had ever known before you would need a chemical laboratory, not a dictionary! (Oldroyd, 1988, pp. 91–92)

On the other hand, the scholars of the new learning were at the same time extremely aware of how crucial to their enterprise was the role that language had to play. Since 'language' now meant 'languages', the perception of this role differed somewhat from one country to another; it was stated most explicitly in England and in France, partly perhaps because of the historical accident that these languages, which had changed catastrophically in the medieval period, were having more trouble sorting out their orthographies than Italian, German or Dutch. Whatever the reason, English and French scholars devoted much effort to designing a language of science; the work in England is described and evaluated by Vivian Salmon in her book *The Study of Language in Seventeenth Century England*, published in 1979. This work went through several phases, as those concerned progressively refined their conception of what it was that was needed to make their language effective as a resource for the new knowledge.

The earliest effort was simply to devise a form of shorthand, a writing system that would be simpler and more expeditious in codifying knowledge in writing; for example Timothy Bright's *Characterie*, published in 1588. Bright's work however already embodied a second, more substantial aim: that of providing a universal charactery, a system of writing that would be neutral among the various different languages, in the way that numerical symbols are. Bright appreciated the lexigraphic nature of Chinese writing (that its symbols stood for words, or their parts), which had then recently become accessible in Europe, and used that as a model for his purpose.

Within the next few decades, a more ambitious goal was being pursued, that of a universal 'philosophical language': that is, a fully designed, artificial language that would serve the needs of scientific research. Among those who conceived of plans for such a philosophical language, Vivian Salmon refers to William Petty, Seth Ward, Francis Lodowick, George Dalgarno and John Wilkins; it was the last of these who actually carried out such a plan to the fullest extent, in his famous *Essay Towards a Real Character and a Philosophical Language*, published in 1668. Wilkins' impressive work was the high point in a research effort in which scholars from many countries had been deeply engaged, as they worked towards a new conception of the structure and organization of scientific knowledge.

A 'philosophical language' was not simply a means of writing down, and hence transmitting, knowledge that had already been gained; more than that, it was a means of arriving at new knowledge, a resource for enquiring and for thinking with. The ultimate goal in the conception of scientific language design was subsequently articulated by Leibniz, who (in Oldroyd's words) 'envisaged the construction of a general science of symbols which could be applied to experience'—a project, however, which 'remained unfulfilled in Leibniz' time and remains so to this day' (op. cit., pp. 104–5). But from the efforts and achievements of Wilkins and his contemporaries, and in particular from the extent to which the scientists themselves supported and participated in these efforts, we can gain a sense of the significance accorded to language in seventeenth-century scientific thought. Language was an essential component in enlarging the intellectual domain.

The biggest single demand that was explicitly made on a language of science was that it should be effective in constructing technical taxonomies. All natural languages embody their own folk taxonomies, of plants and animals, diseases, kinship structures and the like; but these are construed in characteristically messy ways, because of the need to compromise among conflicting criteria, and they were seen rather as an obstacle to developing the systematic technical taxonomies that were required by the new science. So when the scientists came to design their own artificial languages much of the emphasis was placed on building up regular morphological patterns for representing a classificatory system in words.

Clearly this had to be one of the central concerns. Unlike commonsense knowledge, which can tolerate—indeed, depends on—compromises, contradictions and indeterminacies of all kinds, scientific knowledge as it was then coming into being needed to be organized around systems of technical concepts arranged in strict hierarchies of kinds and parts. In the event, none of the artificial languages was ever used for the purpose; but the experience of linguistic design that went into creating them was drawn upon in subsequent work, for example in constructing systematic nomenclatures for use in botany and in chemistry. Even where no special linguistic structures have been developed for the purpose, an essential feature of all scientific registers since that time has been their systems of technical terms.

But there is another aspect of scientific language that is just as important as its technical terminology, and that is its technical grammar. Interestingly, the seventeenth century language planners paid no attention to this. Wilkins' philosophical language did, of course, incorporate a grammar—otherwise it would not have been a language, in any practical sense; but it was a grammar of a conventional kind, without any of the innovatory thinking that had gone into the lexical morphology. Yet if we examine how scientists such as Newton were actually using language in their own writings, we find innovations in the grammar which are no less striking than those embodied in the construction of technical terms. People are, of course, less conscious of grammar than they are of vocabulary; no doubt this is one reason for the discrepancy. The other reason would have been, perhaps, that the grammatical developments were more gradual; they were just one further move in a steady progression that had been taking place since the time of Thales and Pythagoras in ancient Greece, and they did not involve creating new grammatical forms so much as systematically deploying and extending resources that were potentially already there.

It is convenient to think of the new resources that came into scientific English (and other languages: for example the Italian of Galileo) at this time as falling under these two headings, the lexical and the grammatical. The 'lexical' resources were highly visible, in the form of vast numbers of new technical terms; what was significant, however, was not so much the terms themselves as the potential that lay behind them. On the one hand, as we have seen, they could be formed into systematic taxonomic hierarchies; on the other hand, they could be added to *ad infinitum*—today a bilingual dictionary of a single branch of a scientific discipline may easily contain 50,000–100,000 entries. The 'grammatical' resources were the constructions of nominal groups and clauses, deployed so that they could be combined to construe a particular form of reasoned argument: a rhetorical structure which soon developed as the prototypical discourse pattern for experimental science. Any passage of Newton's writings could be taken to illustrate these resources, both the lexical and the grammatical, for example the following passage taken from the *Opticks:*

> If the Humours of the Eye by old Age decay, so as by shrinking to make the *Cornea* and Coat of the *Crystalline Humour* grow flatter than before, the Light will not be refracted enough, and for want of a sufficient Refraction will not converge to the bottom, of the Eye but to some place beyond it, and by consequence paint in the bottom of the Eye a confused Picture, and according to the Indistinctness of this Picture the Object will appear confused. This is the reason of the decay of sight in old Men, and shews why their Sight is mended by Spectacles. For those Convex glasses supply the defect of Plumpness in the Eye, and by increasing the Refraction make the Rays converge sooner, so as to convene distinctly at the bottom of the Eye if the glass have a due degree of convexity. And the contrary happens in short-sighted Men whose Eyes are too plump. (Newton, 1704, pp. 15–16)

This is not the place to discuss such language in detail; the relevant features are taken up specifically in the chapters that follow. But we can illustrate the two sets of resources referred to above. Lexically, expressions such as **Crystalline Humour** (here shown to be a kind of **Humour**), **Refraction** (defined earlier in association with **Reflexion**), **Convex** and **convexity** (contrasted a few lines further down with the **Refractions diminished by a Concave-glass of a due degree of Concavity**) are clearly functioning as technical terms. Grammatically, a pattern emerges in which an expression of one kind is followed shortly afterwards by a related expression with a different structural profile:

> will not be refracted enough...for want of a sufficient Refraction paint(.) a confused Picture...according to the Indistinctness of this Picture
>
> make the Cornea (.) grow flatter...supply the defect of Plumpness in the Eye
>
> those Convex glasses...if the Glass have a due degree of convexity.

In each of these pairs, some verb or adjective in the first expression has been reworded in the second as a noun: **refracted—Refraction**, **confused—Indistinctness**, **[grow] flatter—[the defect of] Plumpness**, **Convex—convexity**; and this has brought with it some other accompanying change, such as **will not be refracted enough—for want of a sufficient Refraction**, **a confused Picture—the Indistinctness of this Picture**. In each case a grammatical process has taken place which enables a piece of discourse that was previously presented as new information to be re-used as a 'given' in the course of the succeeding argument.

But when we observe these two features, technical vocabulary and nominalized grammar, in a passage of scientific text—even a very short extract like the one just cited—we can see that they are interdependent. Creating a technical term is itself a grammatical process; and when the argument is constructed by the grammar in this way, the words that are turned into nouns tend thereby to become technicalized. In other words, although we recognize two different phenomena taking place (as we must, in order to be able to understand them), in practice they are different aspects of a single semiotic process: that of evolving a technical form of discourse, at a particular 'moment' in sociohistorical time.

There is no mystery about this being, at one and the same time, both one phenomenon and two. When we look at it from the standpoint of the wording—lexicogrammatically, or 'from below' in terms of the usual linguistic metaphor—it involves two different aspects of the language's resources, one in the word morphology, the other in the syntax. When we look at it from the standpoint of the meaning—semantically, or 'from above'—we see it as a single complex semogenic process. Lexicogrammatically, it appears as a syndrome of features of the clause; semantically, it appears as a feature of the total discourse. To get a rounded picture, we have to be able to see it both ways.

Here we can, obviously, offer no more than a while-you-wait sketch of one facet of the language of science—although an important one; but it will be enough, perhaps, to enable us to take the next step in our own argument. The language of science is, by its nature, a language in which theories are constructed; its special features are exactly those which make theoretical discourse possible. But this clearly means that the language is not passively reflecting some pre-existing conceptual structure; on the contrary, it is actively engaged in bringing such structures into being. They are, in fact, structures of language; as Lemke has expressed it, 'a scientific theory is a system of related meanings'. We have to abandon the naïve 'correspondence' notion of language, and adopt a more constructivist approach to it. The language of science demonstrates rather convincingly how language does not simply correspond to, reflect or describe human experience; rather, it interprets or, as we prefer to say, 'construes' it. A scientific theory is a linguistic construal of experience.

But in that respect scientific language is merely foregrounding the constructive potential of language as a whole. The grammar of every natural language—its ordinary everyday vocabulary and grammatical structure—is already a theory of human experience. (It is also other things as well.) It transforms our experience into meaning. Whatever language we use, we construe with it both that which we experience as taking place 'out there', and that which we experience as taking place inside ourselves—and (the most problematic part) we construe them in a way which makes it possible to reconcile the two.

Since we all live on the same planet, and since we all have the same brain capacities, all our languages share a great deal in common in the way experience is construed. But within these limits there is also considerable variation from one language to another. Prigogine and Stengers remark, in the Preface to the English translation of their book:

> We believe that to some extent every language provides a different way of describing the common reality in which we are embedded. (Prigogine and Stengers, 1984, p. 31)

—and they are right. Much of this variation, however, is on a small scale and apparently random: thus, the minor differences that exist between English and French (the language in which their book was originally written), while irritating to a learner and challenging to a translator, do not amount to significantly different constructions of the human condition. Even between languages as geographically remote as English and Chinese it is hard to find truly convincing differences—perhaps the gradual shift in the construction of time from a predominantly linear, past/future model at the western end of the Eurasian continent (constructed in the grammar as tense) to a predominantly phasal, ongoing/terminate model at its eastern end (constructed in the grammar as aspect) would be one example, but even there the picture is far from clear. By and large there is a fair degree of homogeneity, in the way our grammars construe experience, all the way from Indonesia to Iceland.

This is not really surprising. After all, human language evolved along with the evolution of the human species; and not only along with it but as an essential component in the evolutionary process. The condition of being human is defined, *inter alia*, by language. But there have been certain major changes in the human condition, changes which seem to have taken place because, in some environments at least, our populations tend inexorably to expand (see for example Johnson and Earle, *The Evolution of Human Societies*; on p. 16 they sum up their findings by saying 'The primary motor for cultural evolution is population growth'). The shift from mobility (hunting and gathering) to settlement (husbanding and cultivating) as the primary mode of subsisting was one such catastrophic change; this may have been associated with quite significant changes in the way experience is construed in language. The classic statement on this issue was made by Benjamin Lee Whorf, in his various papers collected under the title *Language, Thought and Reality*; despite having been 'refuted' many times over this remains as viable as it was when it was first written. More recently, Whorf's ideas have come to be discussed with greater understanding, e.g., by Lee, 1985, Lucy, 1985, and Lucy and Wertsch, 1987.

It would be surprising if there were not some pervasive differences in world view between two such different patterns of human culture. Since some sections of humanity have continued to pursue a non-settled way of life, it ought to be possible to compare the language of the two groups; but this has still not been satisfactorily achieved—for two main reasons. One is that the random, local variation referred to earlier gets in the way; if we focus on grammatical structure, then all types of language will be found everywhere, but it is the underlying 'cryptotypic' grammar that would vary in systematic ways, and we have hardly begun to analyse this. The other reason is that many linguists have felt discouraged by the risk of being attacked as naïve historicists (at best, and at worst as racists if they ventured to suggest any such thing. But to recognize that the changeover from mobility to settlement, where it took place, was an irreversible process is not in any way to attach value to either of these forms of existence. The point is important in our present context, because there appear to have been one, or perhaps two, comparably significant changes in the course of human history, likewise involving some populations and not others; and the 'scientific revolution' was one. (The other, perhaps equally critical, was the 'technological revolution' of the Iron Age.)

Let us be clear what we are saying here. It is not in dispute that, for whatever reason, certain human societies evolved along particular lines following a route from mobility to settlement; among those that settled, some evolved from agrarian to technological, and some of these again to scientific-industrial. The question we are asking is: What part does language play in these fundamental changes in the relationship of human beings to their environment? One answer might be: none at all. It simply tags along behind, coining new words when new things appear on the scene but otherwise remaining unaffected in its content plane (its semantics and its grammar). In this view, any changes that took place in language were merely random and reversible, like the changes from one to another of the morphological language 'types' set up in the nineteenth century (isolating, agglutinative, inflexional).

We reject this view. In our opinion the history of language is not separate from the rest of human history; on the contrary, it is an essential aspect of it. Human history is as much a history of semiotic activity as it is of socio-economic activity. Experience is ongoingly reconstrued as societies evolve; such reconstrual is not only a necessary condition for their evolution—it is also an integral part of it. We have barely started to understand the way this happens (cf. Lemke, 1992); partly because, as already stressed, our descriptions of languages are not yet penetrating enough, but also because we do not yet fully comprehend how semiotic systems work. (We shall come back to this point below.) But while we may not yet understand how meaning evolved, this is no reason for denying that it did evolve, or for assuming that all semantic systems were spontaneously created in their present form.

When we come to consider a special variety of a language, such as the language of science, we may be better able to give some account of how this evolved; not only has it a much shorter history, but also we can assume that whatever special features it has that mark it off from other varieties of the language have some particular significance in relation to their environment. Or rather, we can assume that they had some particular significance at the time they first appeared; it is a common experience for such features to become ritualized over the course of time, once the social context has changed, but it is virtually certain that they would have been functional in origin. We shall try to show, in the chapters which follow, something of the extraordinarily complex ideological edifices which are constructed and maintained by scientific discourse, and how the grammar has evolved to make this discourse possible. We shall also try to show how, in the process, the grammar has been reconstruing the nature of experience.

It is not too fanciful to say that the language of science has reshaped our whole world view. But it has done so in ways which (as is typical of many historical processes) begin by freeing and enabling but end up by constraining and distorting. This might not matter so much if the language of science had remained the special prerogative of a priestly caste (such a thing can happen, when a form of a language becomes wholly ceremonial, and hence gets marginalized). In our recent history, however, what has been happening is just the opposite of this. A form of language that began as the semiotic underpinning for what was, in the worldwide context, a rather esoteric structure of knowledge has gradually been taking over as the dominant mode for interpreting human existence. Every text, from the discourses of technocracy and bureaucracy to the television magazine and the blurb on the back of the cereal packet, is in some way affected by the modes of meaning that evolved as the scaffolding for scientific knowledge.

In other words, the language of science has become the language of literacy. Having come into being as a particular kind of written language, it has taken over as model and as norm. Whether we are acting out the role of scientist or not, whenever we read and write we are likely to find ourselves conjured into a world picture that was painted, originally, as a backdrop to the scientific stage. This picture represents a particular construction of reality; as Prigogine and Stengers remind us,

> Whatever *reality* may mean, it always corresponds to an active intellectual construction. The descriptions presented by science can no longer be disentangled from our [i.e., the scientists'] questioning activity. (Prigogine and Stengers, p. 55)

But it is a picture that is far removed from, and in some ways directly opposed to, the 'reality' of our ordinary everyday experience. Of course, this too is a construct; it is constructed in the grammar of the ordinary everyday language—the 'mother tongue' that first showed us how the world made sense. But that simply makes it harder for us to accept a new and conflicting version. If you feel that, as a condition of becoming literate, you have to reject the wisdom you have learnt before, you may well decide to disengage. The 'alienation' that we referred to at the beginning is in danger of becoming—some might say has already become—an alienation from the written word.

In the chapters which follow, we have tried to present a rounded picture of the language of science the way it has evolved as a variety of present-day English. In Part 1, the perspective is that of a user: that is, scientific English is treated as something 'in place', and then explored both as system (looked at historically) and as process ('at work' in scientific texts). In Part 2, the perspective is that of a learner: the language is presented as something to be mastered, and then explored as a resource for constructing knowledge and achieving control.

In each of these perspectives, we have given prominence to the lexicogrammatical characteristics of scientific writing. We should therefore make it clear that, in concentrating on the grammar, we are not excluding from the picture the generic aspects of scientific discourse; questions of genre are clearly significant (and are in fact taken up in Part 2). The structure of a scientific paper was explicitly debated by the founders of the Royal Society in London; and although ideas have changed about what this structure should be, editors of journals have always tended to impose their rather strict canons of acceptable written presentation, as regards both the textual format and (more recently also) the interpersonal style. But this aspect of scientific discourse has been rather extensively treated (for example in Charles Bazerman's book *Shaping Written Knowledge*); whereas almost no attention has been paid to the distinctive features of its grammar. Yet it is the grammar that does the work; this is where knowledge is constructed, and where the ideological foundations of what constitutes scientific practice are laid down.

The evolution of science was, we would maintain, the evolution of scientific grammar. We do not mean by this scientific theories of grammar—a scientific 'grammatics'; we mean the grammatical resources of the natural languages by which science came to be construed. In case this seems far-fetched, let us make the point in two steps. The evolution of science was the evolution of scientific thought. But thought—not all thought, perhaps, but certainly all systematic thought—is construed in language; and the powerhouse of a language is its grammar. The process was a long and complex one, and it has hardly yet begun to be seriously researched; but we can try, very briefly, to identify some of the milestones along the way. We shall confine our account to western science, because it was in the west that the move from technology into science first took place; but it should be remembered that the original languages of technology evolved more or less simultaneously in the three great iron-age cultures of China, India and the eastern Mediterranean.

As a first step, the early Greek scientists took up and developed a particular resource in the grammar of Greek, the potential for deriving from the lexical stem of one word another word of a different class (technically, the transcategorizing potential of the derivational morphology). Within this, they exploited the potential for transforming verbs and adjectives into nouns. In this way they generated ordered sets of technical terms, abstract entities which had begun as the names of processes or of properties, like **motion**, **weight**, **sum**, **revolution**, **distance**—or in some cases as the names of relations between processes, like **cause**. Secondly, these scholars—and more specifically the mathematicians—developed the modifying potential of the Greek nominal group; in particular, the resource of extending the nominal group with embedded clauses and prepositional phrases. In this way they generated complex specifications of bodies and of figures; these functioned especially as variables requiring to be measured, for example **the square on the hypotenuse of a right-angled triangle**. As in English (where the structure of the nominal group is very similar) this device was applicable recursively; its semogenic power can be seen in mathematical expressions such as the following from Aristarchus of Samos:

> The straight line subtending the portion intercepted within the earth's shadow of the circumference of the circle in which the extremities of the diameter of the circle dividing the dark and the bright portions in the moon move...(Heath, 1913, p. 393)

ed); the relative stability of *x* increases with increasing *y* of *z* (less metaphorically, *x* becomes more stable as *z* acquires more *y*). These examples were not drawn from academic journals; they were taken from randomly opened pages of a senior secondary textbook, a book written for non-specialists, and an issue of the *Scientific American*. Articles written for specialists typically display a considerably denser concentration of grammatical metaphor, which reaches an extreme in the abstracts that are provided at the beginning.

The birth of science, then (if we may indulge in a well-worn lexical metaphor), from the union of technology with mathematics, is realized semiotically by the birth of grammatical metaphor, from the union of nominalization with recursive modification of the nominal group. This emerging variety of what Whorf called 'Standard Average European', instantiated for example in Galileo's Italian and in Newton's English (in reality, of course, a far more complex construction than this brief sketch can hope to suggest), provided a discourse for doing experimental science. The feature we have picked out as salient was one which enabled complex sequences of text to be 'packaged' so as to form a single element in a subsequent semantic configuration.

But by the same token, something else was also happening at the same time. When wordings are packaged in this way, having started off as (sequences of) clauses, they turn into nominal groups, like **the subsequent development of aerogels** nominalized from **aerogels (were) subsequently developed**. It is this nominalization that enables them to function as an element in another clause. But it also has another effect: it construes these phenomena as if they were things. The prototypical meaning of a noun is an object; when **stable**, **behave**, **occur**, **develop**, **useful** are regrammaticized as **stability**, **behaviour**, **occurrence**, **development**, **utility** they take on the semantic flavour of objects, on the model of the abstract objects of a technical taxonomy like **radiation**, **equation** and **mass**. Isolated instances of this would by themselves have little significance; but when it happens on a massive scale the effect is to reconstrue the nature of experience as a whole. Where the everyday 'mother tongue' of commonsense knowledge construes reality as a balanced tension between things and processes, the elaborated register of scientific knowledge reconstrues it as an edifice of things. It holds reality still, to be kept under observation and experimented with; and in so doing, interprets it not as changing with time (as the grammar of clauses interprets it) but as persisting—or rather, persistence—through time, which is the mode of being of a noun.

This is a very powerful kind of grammar, and it has tended to take over and become a norm. The English that is written by adults, in most present-day genres, is highly nominalized in just this way. Discourse of this sort is probably familiar to all of us:

> Key responsibilities will be the investment of all domestic equity portfolios for the division and contribution to the development of investment strategy. (*Sydney Morning Herald*, 1 February 1992, p. 32)

But whereas this nominalizing was functional in the language of science, since it contributed both to technical terminology and to reasoned argument, in other discourses it is largely a ritual feature, engendering only prestige and eighteenth centuries, biological systems in the nineteenth century and social systems in our own twentieth century. Of course, scholars had always been thinking about systems of the more complex kinds, and had tried to account for their special characteristics; already, among the ancient Greek scholars, the Stoics had recognized the need for a special theory of the sign to account for semiotic systems such as language. But in the main currents of thought the natural strategy was to map the more complex system on to a kind that is well understood. Thus the modern period language was modelled first as matter, then as matter plus life; until in the early twentieth century Saussure imported from sociology the concept of value. Since a language is a phenomenon of all these kinds, it was possible to learn a great deal about it; but what was learnt did not yet amount to a science of language, because the special nature of semiotic systems had not yet been understood. Language has a fourth sphere of action, one that lies beyond those of matter, of life and of value; it has **meaning**. The unique property of semiotic systems is that they are systems of meaning.

Meaning arises when a dynamic open system of the social kind—one based on value—becomes stratified. Stratification is the feature that was first adumbrated in the classical theory of the sign; the technical name for the relationship that is brought about by stratifying is **realization**. We discuss below how the concept of realization may best be construed in a theory of language, given that we still understand relatively little about it. Lemke has suggested that it may be formalized through the notion of 'metaredundancy' (1984) as the analogue of the cause and effect of a classical physical system. But it is widely misinterpreted; nearly a century after Saussure there are still those who treat it as if it was a relation of cause and effect, asking about a a stratal relationship such as that between semantics and lexicogrammar the naïve question 'which causes which?'. Realization is a relationship of a very different kind, more akin to that of token and value, where the two can only come into existence, and remain in existence, simultaneously.

Linguists often notice how, when highly sophisticated thinkers from other sciences turn their attention to language, they often ignore altogether the findings of linguistics and regress to treating language at the level at which it is presented in the early years of secondary school. We agree that this is a pity; but we are inclined rather to seek the reason why they do it. To us it seems that this happens because they consider that linguistics has not yet evolved into a science; in the formulation we used earlier, the nature of a 'semiotic fact' is still not properly understood. In our view the twentieth-century scholar who came nearest to this understanding was Hjelmslev, with significant contributions from Whorf, from Firth and from Trubetzkoy; one of the few who have tried to build on Hjelmslev's work is Sydney Lamb. Chomsky oriented linguistics towards philosophy, where it had been located for much of its earlier history; but that did not turn it into a science. As one of the leaders of contemporary linguistics, Claude Hagège, has pointed out, it is the working practices of scientists—how they construct theories to explain the phenomena of experience—that provide the model for those (including linguists) who want to 'do science', rather than philosophers' interpretations of these, which are theories constructed to explain how scientists work.

There is no virtue in doing science for its own sake; and in any case linguistics it accommodates endless random variation of a local kind, in its global evolution it cannot be other than a participant in the social process.

It is a truism to say that we are now in the midst of a period of history when people's lifestyles are changing very fast. With our late twentieth-century technology, many of us no longer spend our time producing and exchanging goods and services; instead, we produce and exchange information. The hub of a city of the industrial revolution was its railway station or its airport, where people and their products were moved around; that of a twenty-first-century city —a 'multi-function polis', as it has been ineptly named—will be (we are told) its information centre, or teleport. The citizens of Osaka, who regard their city as the technological capital of the world (what Osaka thinks today Tokyo will think tomorrow), call it an 'information-oriented international urban complex of the twenty-first century'; its teleport will be

> an information communication base integrating satellite and overland optical fibre network communications systems; it is a port of information communication. (Osaka Port and Harbour Bureau, 1987, p. 7)

In this sort of environment, people will be interfacing more and more with semiotic systems and less and less with social, biological or physical ones—a way of life that is familiar to many human beings already.

As a concomitant of this, scientists are increasingly using semiotic models to complement their physical and biological models of the universe. This began with relativity, as David Bohm makes clear:

> A very significant change of language is involved in the expression of the new order and measure of time plied *[sic]* by relativistic theory. The speed of light is taken not as a possible speed of an *object*, but rather as the maximum speed of propagation of a *signal*. Heretofore, the notion of signal has played no role in the underlying general descriptive order of physics, but now it is playing a key role in this context.
>
> The word 'signal' contains the word 'sign', which means 'to point to something' as well as 'to have significance'. A signal is indeed a kind of *communication*. So in a certain way, significance, meaning, and communication become relevant in the expression of the general descriptive order of physics (as did also information, which is, however, only a *part* of the content or meaning of a communication). The full implications of this have perhaps not yet been realized, i.e., of how certain very subtle notions of order going far beyond those of classical mechanics have tacitly been brought into the general descriptive framework of physics. (Bohm, 1980, p. 123)

Many physical, chemical and biological phenomena are coming to be interpreted as semiotic events. Prigogine and Stengers give the example of periodic chemical processes ('chemical clocks') that occur in far-from-equilibrium states of matter:

> Suppose we have two kinds of molecules, 'red' and 'blue'. Because of the chaotic motion of the molecules, we would expect that at a given moment

we would have more red molecules, say, in the left part of a vessel. Then a bit later more blue molecules would appear, and so on. The vessel would appear to us as 'violet', with occasional irregular flashes of red or blue. However, this is *not* what happens with a chemical clock; here the system is all blue, then it abruptly changes its colour to red, then again to blue. Because all these changes occur at *regular* time intervals, we have a coherent process.

Such a degree of order stemming from the activity of billions of molecules seems incredible, and indeed, if chemical clocks had not been observed, no one would believe that such a process is possible. To change colour all at once, molecules must have a way to 'communicate'. The system has to act as a whole. We will return repeatedly to this key word, communicate, which is of obvious importance in so many fields, from chemistry to neurophysiology. Dissipative structures introduce probably one of the simplest physical mechanisms for communication. (Prigogine and Stengers, 1984, pp. 147–8)

Here 'communicate' is picked out as a 'key word', a word that is 'of obvious importance in so many fields'. But this, in fact, is where we have to demur. The word 'communicate' in itself is of very little importance; nor is the fact that 'the word "signal" contains the word "sign"', whatever that 'contains' is taken to mean. What is important is the system of meanings that constitute a scientific theory of communication (that is, of semiotic systems and processes), and the lexicogrammatical resources (the 'wordings' as a whole) by which these meanings are construed.

And here we come to a problem and a paradox. The problem is this. The language of science evolved in the construal of a special kind of knowledge—a scientific theory of experience. Such a theory, as we have said, is a semiotic system; it is based on the fundamental semiotic relation of realization, inhering in strata or cycles of token and value. But this means that scientists have all along been treating physical and biological processes as realizations—and hence as inherently communicative (Prigogine and Stengers refer to science as 'man's dialogue with nature'). (We are using 'system' always as a shorthand term for 'system-and-process'; communicating is simply semiotic process.) The problem, now that semiotic systems are being explicitly invoked as explanatory models in science, is to direct the beam of scientific enquiry on to such systems and study them as phenomena in their own right. They can hardly serve an explanatory role if they are not themselves understood.

The prototype of a semiotic system is, as we have said, a natural language; and this leads us in to the paradox. In adapting natural languages to the construction of experimental science, the creators of scientific discourse developed powerful new forms of wording; and these have construed a reality of a particular kind—one that is fixed and determinate, in which objects predominate and processes serve merely to define and classify them. But the direction of physics in the twentieth century has been exactly the opposite: from absolute to relative, from object to process, from determinate to probabilistic, from stability to flow. Many writers have been aware of the contradiction that this has brought about, and have hoped somehow to escape from it by redesigning the forms of language—

without realizing, however, that it is not language as such, but the particular register of scientific language, that presents this overdeterminate face. The language they learnt at their mothers' knees is much more in harmony with their deepest theoretical perceptions.

So while there is no reason to doubt that the language of science, as a variety of present-day English (and its counterpart in other languages), will continue to evolve in the twenty-first century, we may expect that it will change somewhat in its orientation. It is likely to shift further towards semiotic explanations, both at the highest level of scientific abstraction and at the technological level in line with the 'information society' (the vast output of computer documentation has already constituted a special sub-register at this level). But at the same time it is likely to back off from its present extremes of nominalization and grammatical metaphor and go back to being more preoccupied with processes and more tolerant of indeterminacy and flux.

In order to do this while still functioning at the technical and abstract level of scientific discourse the grammar would need to be restructured in significant ways. This would not be a matter of inventing a few new verbs; it would mean recasting the nominal mode into a clausal one while developing the verbal group as a technical resource. Note in this connection Whorf's observation about Hopi:

> Most metaphysical words in Hopi are verbs, not nouns as in European languages… Hopi, with its preference for verbs, as contrasted with our own liking for nouns, perpetually turns our propositions about things into propositions about events. (Whorf, 1950, pp. 61–63)

It is doubtful whether this could be done by means of design; a language is an evolved system, and when people have tried to design features of language they have almost always failed—although it has to be said that they have usually done so without knowing much about what language is or how it works. But however it came about, any change of this kind would have important social consequences, because it would help to lessen the gap between written language and spoken, and between the commonsense discourse of home and neighbourhood and the elaborated discourse of school and the institutions of adult life.

Two other factors seem to tend in the same direction. One is the way that information technology has developed. The semotechnology of the scientific revolution was print; this made the written language predominant, and greatly exaggerated the difference between writing and speech. Eventually the status of writing was undermined by speech technology—telephone and radio; this redressed the balance somewhat but did not bring the two closer together. The disjunction is being overcome, however, by tape recorders and computers: spoken language can now be preserved through time as text, while written language can be scrolled in temporal sequence up the screen. Instead of artificially forcing the two apart, the new technology tends to mix them up together; as happens for example in electronic mail, which is an interesting blend of spoken and written forms.

But there is another, deeper tendency at work, a long-term trend—however faltering and backtracking—towards more democratic forms of discourse. The

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