ISSUES AND TRENDS

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Scientific Literacy: A Systemic Functional Linguistics Perspective

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ABSTRACT: Scientific writing contains unique linguistic features that construe special realms of scientific knowledge, values, and beliefs. An understanding of the functionality of these features is critical to the development of literacy in science. This article describes some of the key linguistic features of scientific writing, discusses the challenges these features present to comprehension and composition of science texts in school, and argues for greater attention to the specialized language of science in teaching and learning. © 2004 Wiley Periodicals, Inc. *Sci Ed* **89:**335–347, 2005

INTRODUCTION

> Knowing and understanding the language of science is an essential component of scientific literacy. (Wellington & Osborne, 2001, p. 139)

"In a world filled with the products of scientific inquiry, scientific literacy has become a necessity for everyone" (NRC, 1996, p. 1). An understanding of science and the processes of science is essential to full participation in life. Despite the centrality of science to our life and to the progress of our society, many students fail to acquire

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scientific knowledge, understanding, and abilities. According to the 2000 National Assessment of Educational Progress (NAEP) science assessment (NCES, 2003), over two-thirds of 8th graders and three-quarters of 12th graders perform below the proficiency level. Moreover, the 2000 NAEP results show no significant change in grades 4 and 8, and a decline in performance at grade 12 since 1996. The following statement by Lemke (2001, p. v) effectively captures the disturbing state of science education in American schools:

> Too many pupils care less and less for science as a school subject the more 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).

What is it about science that makes it so alienating to students? Many factors are at work here, but, as several scholars (e.g., Lemke, 1990; Wellington & Osborne, 2001) have suggested, the biggest barrier to the learning of science is the language of science itself. Why is scientific language so important to the learning of science? What are its characteristics? Why do students tend to be turned off by scientific language?

In this paper, I describe several key features of scientific writing and discuss the challenges these unique features present to comprehension and composition of science texts in school. To this end, I draw primarily on the very substantive body of work that has been done on this topic from a systemic functional linguistics (SFL) perspective (e.g., Halliday & Martin, 1993; Martin & Veel, 1998; Schleppegrell, 2004; Unsworth, 2001). Finally, I briefly critique the current emphasis on inquiry science and argue for a more balanced science pedagogy that attends to both empirical activities and the specialized language of science. Although scientific genres are typically multimodal and scientific meanings are often conveyed through a combination of words, images, diagrams, and mathematical/graphical signs (see Lemke, 1998; Unsworth, 2001), for purpose of this discussion, I chose to focus on the verbal resource used in science text. Moreover, I view scientific literacy in both its "fundamental" sense (i.e., being able to read/write science texts) and "derived" sense (i.e., being knowledgeable about the contents of science contents) (see Norris & Phillips, 2003), and contend that the two senses of scientific literacy are indeed interrelated and inseparable in the context of modern Western science.

A FUNCTIONAL VIEW OF LANGUAGE

Traditionally, language has been thought of as merely a kind of vehicle that transmits thought or reality. Systemic functional linguistics (see Halliday, 1978, 1994; Hasan & Martin, 1989) reconceptualizes language as a semiotic tool intimately involved in the negotiation, construction, organization, and reconstrual of human experiences. It demonstrates how linguistic choices (i.e., grammar) contribute in a systematic way to the realization of social contexts. In this conception, language is more than a conduit of meaning; it is a principal resource for making meaning. It is simultaneously "a part of reality, a shaper of reality, and a metaphor for reality" (Halliday, 1993a, p. 8).

Scholars (e.g., Halliday, 1994; Martin, 1992) have shown that language is indeed an open-ended yet interlocking system of options. As such, language allows its users to make certain lexicogrammatical choices that suit personal needs and are appropriate for particular social contexts. Through selection of particular lexicogrammatical items available in language, speakers and writers are able to simultaneously engage in presentation of topic, negotiation of role relationship, and structuring of text (Schleppegrell, 2004). Texts (oral and written) produced in different contexts thus contain different linguistic features and realize different social functions. As Christie and Martin (1997) have suggested, variations in language use express the diversity of structures and processes in the social system.

Based on this functional view of language, it is expected that the language used to construe scientific knowledge and values should be quite distinct from other varieties (registers) of language, because the structures and functions of scientific activities are markedly different from those of other realms of human endeavors. Related to this point, Roth and Lawless (2002) have argued that science is, indeed, "a form of culture with its own creeds, language, material practices, perceptions, theories, and beliefs" (p. 369). Central to the establishment of the science culture is its language. In his discussion of the evolution of the language of science, Halliday (1993b) clearly demonstrated that the very circumscribed way of investigating the physical world in science (i.e., recognizing a problem, making a hypothesis, designing an experiment, collecting data, analyzing data, drawing a conclusion) has given rise to a distinct variety of language as a means of producing and organizing scientific knowledge. This new register, often referred to as scientific language, meets "the needs of scientific method, and of scientific argument and theory" (Halliday, 1993d, p. 84). It contains unique lexicon, syntax, semantics, and structure, which enable scientists to conduct specialized kinds of cognitive and semiotic work, including, for example, the theorizing of everyday life experiences as well as phenomena that are far removed from everyday life.

Unlike the language of everyday spontaneous speech, which is functional for construing commonsense knowledge in the context of everyday ordinary life, scientific language is functional for construing special realms of scientific knowledge and beliefs. As such, it embodies a unique worldview and way of thinking and reasoning. The specialized grammar of scientific language makes it possible for scientists to construct an alternative interpretation of the physical world to that provided by the commonsense language of everyday spontaneous speech (Halliday & Martin, 1993; Martin & Veel, 1998).

From the perspective of functional linguistics, learning the specialized language of science is synonymous with learning science. According to Halliday (1993c), "language is the essential condition of learning, the process by which experience becomes knowledge" (p. 94). Learning science means learning to control the unique linguistic forms and structures that construct and communicate scientific principles, knowledge, and beliefs. Thus, developing literacy in science is fundamentally a semiotic process involving systematic remodeling of everyday grammar and concomitant resconstrual of everyday ordinary life experiences (Wells, 1994).

SPECIAL FEATURES OF SCIENTIFIC WRITING

As noted earlier, science cannot be done using everyday ordinary language; rather, it is constructed through specialized grammar. Such a grammar is functional in that it facilitates effective presentation of information and development of argument in science (Schleppegrell, 2001). At the same time, however, it also renders scientific writing particularly dense, technical, and abstract. In this section, I describe several key aspects of the grammar of scientific language and discuss the comprehension and composition challenges these features present to students, who are typically used to the more familiar and concrete social language of everyday spoken interaction. To illustrate my points, I draw examples from popular elementary and middle school textbooks, including *Science* for fifth grade (Scott Foresman, 2000), *Science Voyages* for sixth grade (Glencoe/McGraw-Hill, 2000), and *Science Explorer* (including Life, Earth and Environmental Sciences) for middle school (Prentice Hall, 2001).

Informational Density

One of the distinguishing features of scientific writing is that it has a high density of information. The informational density of a text can be measured by an index called "lexical density." Lexical density can be calculated in two ways: (a) as the number of content (i.e., lexical) words per nonembedded clause (Halliday, 1993d), or (b) as the percentage of content words over total running words (Eggins, 1994). Content carrying words include nouns, the main part of the verb, adjectives, and some adverbs; noncontent carrying words include prepositions, conjunctions, auxiliary verbs, some adverbs, determiners, and pronouns (Eggins, 1994). A clause typically consists of participants (as expressed by nouns), processes (as expressed by verbs), and circumstance (as expressed by adverbial or prepositional phrases) (Eggins, 1994). In scientific writing, more content words are packed into the clause; whereas in everyday spontaneous speech, noncontent words make up a significant part of the clause. According to Halliday (1993d), in everyday spontaneous speech, there are usually 2–3 content words per clause; however, in written language there are 4–6 content words per clause. In scientific writing, this number can become considerably higher, sometimes as high as 10–13 content words per clause. Text 1 (see Figure 1), for instance, has a total of 38 content words in 6 clauses (or 68 total words), yielding a lexical density of 6.33 (or 56%). This density of information is achieved partly through the use of longer and more complex noun phrases such as *a disorder in which the respiratory passages narrow significantly* and *the substances and activities that trigger attacks*. These extended noun phrases condense information that would normally be expressed, as in everyday spontaneous speech, with more than one clause. For example, the first clause in Text 1 can be expressed in everyday language in three clauses: *Asthma is a disorder. // It occurs // when the respiratory passages narrow a lot*.

Other samples of extended noun phrases from major elementary and middle school textbooks are listed in Figure 2. As these examples demonstrate, an extended noun phrase, such as *the lush, green plant growth of the tropic rain forest*, typically consists of a head noun (e.g., *growth*) with pre- and/or postmodifiers. Premodifiers can include deictic, as expressed by determiners and pronouns (e.g., *the, these*); epithet, as expressed by adjectives (e.g., *lush, green*); and/or classifier, as expressed by nouns (e.g., *plant*). Postmodifiers are typically served by prepositional phrases (e.g., *of the tropical rain forest*, *in the equatorial regions of the world, with a definite chemical structure*) and/or embedded clauses (e.g., *... formed from the remains of once-living organisms*; *... in which new individuals are added to a population*; *... made up of different types of tissues that work together to do a particular job*). Due to their compacting of information, extended noun phrases can pose considerable challenges for reading comprehension, because of the information load they impose on human working memory (see Miller, 1969). Students may feel overwhelmed by the density of information during text processing. They may also be confused by the embedded and often

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Asthma is a **disorder** in which the **respiratory passages narrow significantly**. // This **narrowing causes** the **person** to **wheeze** and **become short** of **breath**. // **Asthma attacks** may be **brought** on by **factors** other than **allergies**, such as **stress** and **exercise**. // **Severe asthma attacks** may **require emergency medical care**. // **People** who have **asthma** can **prevent asthma attacks** with **medication**, // or they can **avoid** the **substances** and **activities** that **trigger attacks**.

Figure 1. Text 1. Clause boundaries are marked with //. Content words are in bold. Clause themes are underlined. From *Science Explorer: Life Science* (Prentice Hall, 2001, p. 613).

- The most important climax community in the equatorial regions of the world is the lush, green plant growth of the tropic rain forest.
- An organ is a structure made up of different types of tissues that work together to do a particular job.
- A mineral is a natural, nonliving solid with a definite chemical structure.
- Fossil fuels are the energy-rich substances formed from the remains of once-living organisms.
- An especially important factor in water biomes is sunlight.
- A bird is an endothermic vertebrate that has feathers and a four-chambered heart, and lays eggs.
- The major way in which new individuals are added to a population is through the birth of offspring.
- Another example of how scientists combined evidence from different sources is shown in the branching tree in Figure 16. A branching tree is a diagram that shows how scientists think different groups of organisms are related.

Figure 2. Examples of extended noun phrases from science textbooks. Extended noun phrases are underlined.

imbalanced nature of the clause structure. For example, the lengthiness of subjects and/or objects can hinder reading fluency and obstructs nonproficient readers from constructing a coherent mental representation of the message presented in the clause. Students who do not understand the meaning-making potential of extended noun phrases are not likely to use it effectively in their own writing.

Abstraction

A second, but related, feature of scientific writing is abstraction. Unlike the commonsense language used for construing everyday life experiences, scientific language theorizes concrete life experiences into abstract entities, which can then be further examined and critiqued. Such theorizing involves turning processes (as expressed by verbs and adjectives) into participants (as expressed by nouns). This remodeling of grammar, from verbs or adjectives into nouns, is referred to as "nominalization" (Halliday, 1998). According to Christie (2001, p. 66), nominalized phrases "abstract away from immediate, lived experiences, to build instead truths, abstractions, generalizations, and arguments," so that they can further participate in the process. Nominalization allows the author to create technical terms or new entities, to establish cause-and-effect relationships between disparate phenomena, and to synthesize and systematize previously stated information (Veel, 1997, p. 184). In Text 1, for example, the event in the first clause (i.e., the respiratory passages narrow significantly) is turned into an abstract noun (i.e., *this narrowing*) in the second clause, which enables the author to continue discussion on the topic. Similarly, the events in the second clause (i.e., wheeze and become short of breath) are subsequently synthesized into "*asthma attacks*" so that further comments can be made about it. In the fifth clause, the abstract noun "*medication*" is used, instead of the more congruent form "taking medicine," as a participant in the process of preventing asthma attacks. Other examples of nominalization from elementary and middle school textbooks are listed in Figure 3.

Nominalization involves more than remodeling of grammar (or re-grammaticizing), however. It also is a process of re-meaning or re-semanticizing (Halliday, 1998). When an action

- The air at the bottom of the atmosphere, close to Earth, is more dense. This dense air exerts more force than the less-dense air at the top of the atmosphere.
- But as Earth rotates, the paths of the winds and currents curve in relation to Earth's surface. This effect of Earth's rotation on the direction of winds and currents is called the Coriolis effect.
- They [farmers] adopted methods of farming that helped saved the soil. Soil conservation is the management of soil to prevent its destruction.
- During combustion, the carbon and hydrogen combine with oxygen in the air to form carbon dioxide and water. This process releases energy in the forms of heat and light.
- As a matter of fact, light waves do bend around the edges of an open door. You can see some effects of light diffraction when you view a bright light through a small slit such as the one between two pencils held close together.
- While some layers contain gases that easily absorb the sun's energy, other layers do not. Because of this, the various layers have different temperature.
- The most important characteristic of placental mammals is that their embryos develop in the uterus of the female. This time of development, from fertilization to birth, is the gestation period.
- Many insect species breed in the warm spring weather. As winter begins, the first frost kills many of the insects. This sudden rise in the death rate causes the insect population to decrease.
- Gasoline or oil that leaks from an underground tank is hard to clean up. If the pollution has not spread far, the soil around the tank can be removed.
- When a large asteroid hit Earth 65 million years ago, it exploded, making a crater 200 kilometers in diameter near the Yucatan Peninsular of Mexico. The explosion almost certainly raised trillions of tons of dust into the atmosphere, blocking the light from the sun for months.

Figure 3. Examples of nominalization from science textbooks. Nominalized phrases are underlined.

or event is reworded as a nominal group, much of the semantic information becomes lost or, rather, hidden, and ambiguity often sets in. For example, the nominalized phrase—*the destruction of Brazilian rainforest*—might be interpreted as the realization of "People cut down trees in Brazilian rainforest," "Trees in Brazilian rainforest are cut down (by logging companies)," "Brazilian rainforest is destroyed (by people or natural disasters)." It effectively suppresses agency, hiding the party responsible for destroying the rainforest. Similarly in Text 1, *this narrowing* raises questions about "what is being narrowed," "what is the extent of the narrowing," and "what causes the narrowing." *Asthma attacks,* on the other hand, buries the specific symptoms of asthma, such as wheezing and becoming short of breath. Nominalization can, therefore, create problems for readers, because it tends to neutralize or obscure meanings and construct an ideology that is often not transparent to naïve readers. Readers will have to recover the hidden meanings and resolve ambiguities in order to gain full understanding. Students who are not familiar with this way of making meaning and constructing text often fail to identify the precise referents of nominalized phrases and get frustrated with the ambiguity that nominalization engenders. Moreover, without an acute understanding of the role nominalization plays in fashioning scientific texts, students will not be able to present information and develop argument effectively in their own writing (Schleppegrell, 2004).

It should become evident by now that scientific writing has a particular preference for nouns, especially the extended and nominalized ones. According to Halliday and Martin

(1993), the evolution of scientific language has been one that foregrounds participants and backgrounds actions and processes:

> Where the everyday 'mother tongue' of commonsense knowledge construes reality as a balanced tension between things and processes, the elaborated register of scientific knowledge construes 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... but as persisting—or rather, persistence—through time, which is the mode of being a noun. (p. 15).

This privileging of nouns is not surprising. Science is a discipline that involves defining, comparing, characterizing, classifying, and explaining, as well as building arguments for/against hypotheses made about, the phenomena in the natural world. Nouns are an especially powerful resource for this purpose. They can synthesize or abstract previously presented information into entities, which can then become grammatical participants in subsequent discussion. As such, they are a particularly effective tool for "creating a flow of discourse" in science (Halliday, 1998, p. 202). An examination of clause themes brings this point to light. Theme is the first constituent in a clause that serves as the point of departure for the message (Halliday, 1994). It typically contains familiar information, i.e., information that is known from the context or has been previously mentioned in the text (Eggins, 1994, p. 275). Themes can be identified as the linguistic elements "up to and including the first experiential [i.e., topical] element at the beginning of a clause" (Schleppegrell, 2004, p. 68). Themes in scientific English can be realized by nominal phrases (e.g., *Fossil fuels are hydrocarbons*.), verb phrases (e.g., *Winning measurements for some events are given with more precision over time*.), conjunctive phrases (e.g., *Like all electromagnetic waves*, *light is a transverse wave*.), or prepositional phrases (e.g., *In trying to predict earthquakes*, *geologists have invented instruments to record the ground movements that occur along faults*.). However, as Text 1 demonstrates, themes in scientific writing are most often realized by nouns, many lengthy (e.g., *people who have asthma, severe asthma attacks*) and others short. Where simple or short nouns are used as themes, they typically refer to classes of things/people (e.g., *asthma*, *they*) or abstract entities (e.g., *this narrowing, asthma attacks*). Together, these nouns help establish semantic links among clauses and contribute to the overall discursive flow in the text. This is unlike in everyday spontaneous speech, where themes are typically pronominalized (e.g., *it, they*) and frequently preceded by continuity items (e.g., *hey, oh, well*), interpersonal items (e.g., *maybe, did, would*), additive conjunctions (e.g., *and, so*), and/or other resources that introduce dependent clauses (e.g., *if, because*) (Eggins, 1994; Schleppegrell, 2001).

Technicality

The third feature of scientific writing is technicality. Technicality is necessary in order to realize the specialized contents of science. The process of "technicalizing" in science typically involves the use of technical vocabulary and verbs of relational processes. Technical vocabulary refers to "terms or expressions . . . with a specialized field-specific meaning (Wignell, Martin, & Eggins, 1993, p. 144). Most science textbooks explicitly mark these words in bold type. Technical terms can be names for the physical objects or phenomena in the natural world (e.g., *mineral, endothermic vertebrate*, *respiratory passages*, *asthma, climax community, the Coriolis effect*). These words or phrases allow scientists to construct classes/categories and establish taxonomic relationship among entities in the natural world. Additionally, technical terms can be nonvernacular adjectives that describe these physical objects/phenomena (e.g., *multicellular, nocturnal*) or verbs that describe unique activities or processes of a specialized discipline (e.g., *wheeze*, *evaporate, condense, congregate*). They can also derive from nominalization (e.g., *condensation, narrowing*, *stretchings*). As such, technical terms always function at a somewhat abstract level (Halliday, 1998). Many commonsensical terms also count as technical vocabulary when they are used with specialized meanings or in a metaphorical sense. For example, all the underlined words in Figure 4 connote something other than their vernacular meanings and are thus considered technical terms as well. Students who do not know the meanings of technical vocabulary are almost certain to struggle with comprehension of science texts. Without control over technical vocabulary, students will lack the grammatical resource needed to accurately and effectively communicate scientific ideas and knowledge.

Verbs of relational processes, on the other hand, are verbs or verb phrases that can be used to define (e.g., *are, is called*), classify (*are made of, belong to*), compare/contrast (e.g., *is younger than, have twice as much*), or characterize (e.g., *is vicious, have sharp claws*) the thing in question. They serve to relate known commonsense terms or previously defined technical terms to new technical ones (Veel, 1997). As such, they are an important resource for describing/explaining the experiential world and for establishing taxonomic relationship in scientific theorizing. Students who are not aware of these linguistic resources will have difficulties constructing scientific knowledge and communicating scientific information effectively in their own writing.

Authoritativeness

An additional feature of science writing is its authoritativeness. In science, information is typically presented accurately and objectively, as well as in an assertive tone (Schleppegrell, 2001). In order to do so, the author must distance him/herself from the text by refraining from using (a) first person references (e.g., *I am writing...*), (b) references to his/her mental processes (e.g., *I think, I suppose*), (c) discourse fillers for monitoring information flow (e.g., *you know. well*), (d) direct quotes (e.g., *it says, "I am tired."*), and (e) vagueness and hedges (e.g., *sort of, stuff like that*) (Chafe, 1982). In scientific writing, authoritativeness is typically conveyed through the use of technical, rather than commonsense, vocabulary (e.g., *asthma*); declarative, rather than imperative or interrogative, sentences (e.g., *Severe*

- Asthma is a disorder in which the respiratory <u>passages</u> narrow significantly.
- <u>Soft water</u> leaves fewer deposits and forms better soapsuds than <u>hard water</u>.
- Movements along <u>faults</u> can make it harder for geologists to determine the relative ages of rock layers.
- Pure metals that crystallize underground from hot water <u>solutions</u> often form <u>veins</u>.
- Whether a mineral has <u>cleavage</u> depends on how the atoms in its crystals are arranged.
- When <u>runoff</u> flows in a thin layer over the land, it may cause a type of erosion called <u>sheet</u> erosion.
- The bodies of most <u>sponges</u> have irregular shapes, with no symmetry.
- Many birds have an internal storage tank, or <u>crop</u>, that allows them to store food inside the body after swallowing it.
- If the <u>host</u> dies, the parasite loses its source of food.

Figure 4. Examples of commonsense words with specialized meanings from science textbooks. Commonsensical terms with specialized meanings are underlined.

asthma attacks may require emergency medical care.); and passive, rather than active, voice (e.g., *Asthma attacks may be brought on by factors other than allergies*. . .). Together, these grammatical resources enable "the realization of an assertive author who present him/herself as a knowledgeable expert providing [accurate and] objective information" (Schleppegrell, 2001, pp. 444–445). Because of its authoritativeness, scientific language is distinct from the more informal and engaging language of everyday ordinary life. It appears both impersonal and alienating to students who are generally used to the more familiar and interactive language of everyday spontaneous speech.

Current science textbooks do make some use of language that is more informal and interactive, such as interrogative and imperative clauses (e.g., *Have you ever been inside a greenhouse during the winter? Imagine watching a cosmic collision!*), as well as active voice (e.g., *You can think of a comet as a "dirty snowball" about the size of an Earth mountain*.). These devices feature greater involvement between the author and the reader. They make scientific texts appear more personal and less alienating. They are meant to draw readers into the text and to stimulate their engagement. However, as Schleppegrell (2004) has argued, if these informal linguistic features are not carefully juxtaposed with the more authoritative language of science, incoherent registers can arise. Grossly mixed registers provide a poor model of scientific discourse and can cause comprehension difficulties for students.

Summary

Scientific writing contains a number of unique features that encode specialized knowledge, values, and worldviews of the scientific community. These features are realized through the deployment of a distinct set of lexicogrammatical resources. These linguistic resources do not, however, occur in isolation. Rather, they typically co-exist and interact in synergistic ways to construct an alternative interpretation of the natural world to that offered by the commonsense language of everyday ordinary life (Halliday & Martin, 1993). A comparison of several key indices for the two brief texts in Table 1 highlights the striking differences between scientific language and everyday ordinary language. Students who are not familiar with the specialized meaning-making grammatical resources of science are likely to experience significant difficulties when reading and writing science texts. As Wellington and Osborne (2001) aptly pointed out, ". . . for many pupils, the greatest obstacle in learning science—and also the most important achievement—is to learn its language" (p. 3).

EDUCATIONAL IMPLICATIONS

It has been suggested that scientific language typifies the kind of language privileged in school and society (Christie & Martin, 1997; Schleppegrell, 2004). Thus, success in mastering this "power code," however exoteric, will go a long way toward ensuring students' success in school and beyond. Because scientific language evolves for functional, rather than status, reasons in response to newly emerging social contexts (Halliday & Martin, 1993), it has to be dealt with in school and cannot simply be dismissed as technocratic, hegemonic, patriarchal, or oppressive. Students need tools for unpacking and strategies for revealing "the organization and logic of scientific ways of using language" (Lemke, 2001, p. v), so that they are empowered to effectively consume and critique the discourses of science. In this connection, Martin (1998) has argued that schools have a responsibility to engage students in explicit learning of scientific language. Along the same vein, Wellington and Osborne (2001, p. 139) advocated,

TABLE 1
Comparison of Scientific Language with Everyday Ordinary Language

	Everyday Ordinary Language	Scientific Language
Text	We **need** our **forest** // because **plants** can **turn** **carbon dioxide** into **oxygen** // and if we didn't have **oxygen** // we would **die**. // **People** are **worried** // that if the **rainforest** in **Brazil** is **cut** down // the **earth** will not have enough **oxygen** to **keep humans** and **animals alive**. (Derewianka, 1999, p. 24)	Our **reliance** on **forest vegetation** for its **life-sustaining capacity** to **generate oxygen** through **photosynthesis** had **led** to **concern** that the **destruction** of **Brazilian rainforest** will **result** in **depleted supplies** of **oxygen**. (Derewianka, 1999, p. 24)
Number of clauses	7	1
Lexical density	20/7 = 2.86	18/1 = 18.00
Number of nominalized phrases per clause	0/7 = 0.00	6/1 = 6.00 * we need =>> our reliance * can turn carbon dioxide into oxygen =>> capacity to generate oxygen * we would die =>> life-sustaining * are worried =>> concern * cut down =>> the destruction * will not have enough oxygen =>> depleted supplies of oxygen
Number of technical words or phrases per clause	5/7 = 0.71 (carbon dioxide, oxygen, rainforest, oxygen, oxygen)	10/1 = 10.00 (reliance, forest vegetation, life-sustaining capacity, generate, oxygen, photosynthesis, destruction, rainforest, depleted supplies, oxygen)
Clause theme	Clause 1: We Clause 2: because plants Clause 3: and if we Clause 4: we Clause 5: People Clause 6: that if the rainforest in Brazil Clause 7: the earth	Clause 1: Our reliance on forest vegetation for its life-sustaining capacity to generate oxygen through photosynthesis

Clause boundaries are marked with // and content words are in bold.

> In short, teaching about the use of language of science is not an optional extra but central to the process of learning science. For without a sense of why it is that science is written in these strange and unfamiliar forms, and what the words mean in the context of their use, science will simply remain a foreign language [to students].

Current recommendations for science pedagogy (e.g., AAAS, 1993; NRC, 1996; Rutherford & Ahlgreen, 1990; Victor & Kellough, 2000) do not, however, demand such attention to the specialized language of science. Instead, they emphasize gaining experiences with natural and social phenomena through hands-on observation and experiment, while seemingly loosing sight of the very means through which scientific knowledge is typically constructed. The National Research Council (1996, 2000), for example, has recently outlined a new vision of science education that makes inquiry the cornerstone of the science curriculum. Embedded in this notion of inquiry science is the recognition that science is a process for producing knowledge that "depends both on making careful observations of phenomena and on inventing theories for making sense out of those observations" (Rutherford & Ahlgreen, 1990, p. 4). There is no question that empirical activities are both necessary and important in science learning. They have the potential to help students understand science as a human endeavor, build concrete experiential background for understanding science texts, acquire scientific knowledge and thinking skills important in everyday life, and develop an interest in science.

There is more to science than empirical work, however. According to Halliday (1998), science is "one and the same time both material and semiotic practices" (p. 228). This means that scientific work is in part an exercise in lexicogrammar. To become scientifically literate, students must ultimately learn to cope with the specialized language of science. For example, students must be able to read and comprehend texts where scientific knowledge and ideas are typically presented in school. They must also be able to employ appropriate linguistic resources to communicate what they have learned from empirical activities and from what they have read. Knowledge and understanding of scientific language is critical to the development of scientific literacy in both its "fundamental" sense (i.e., ability to read/write science text) and "derived" sense (i.e., knowledgeability about science) (see Norris & Phillips, 2003). Students who do not appreciate and understand the specialized language of science will be severely handicapped in their learning of scientific principles, knowledge, and values. If we accept the views that empirical activities are "the handmaidens to the rational activity of generating arguments in support of new ideas about the way the world behaves" and that "understanding the language of science is sine qua non to understanding the ideas of science" (Wellington & Osborne, 2001, p. 140), we must then give greater attention to the linguistic resources that construe scientific beliefs and knowledge. An inquiry-based curriculum, when coupled with an explicit focus on the specialized language of science, will have the best potential to maximize learning and promote scientific literacy for all students.

The foregrounding of language in science teaching and learning demands that teachers have a better understanding of the central role language plays in shaping experience/reality and hence in learning, so that they can become more proactive and effective in apprenticing students to the discourse community of science. Norris and Phillips (2003) maintained that modern western science is dependent on written text. This means that learning science in school necessarily involves learning to cope with the specialized language of science. It has been argued that learning scientific language and learning the contents of science (e.g., its principles, knowledge, and values) are essentially one and the same thing (Christie, 1989; Halliday, 1993d; Schleppegrell, 2004; Wellington & Osborne, 2001). From this perspective, science teachers are simultaneously teachers of language/reading. After all, school subjects such as science are mediated primarily through written language, and it is through the use of such language that teachers are able to assess and promote students' learning of science.

Despite the centrality of language in science learning and the imperative for an explicit focus on scientific language, science teachers typically view their job as teaching the contents of their subject and do not consider themselves as teachers of reading/language (O'Brien, Stewart, & Moje, 1995). Some even seek and are encouraged, to eliminate text from science instruction. Moreover, according to Draper (2002), current science textbooks continue to show a lack of explicit encouragement for reading instruction and provide little assistance to science teachers in understanding and teaching the specialized language of science. In a relatively recent national survey, Shymansky, Yore, and Good (1991) found that science teachers often place high priority on content coverage and lack the knowledge and expertise to provide reading/language instruction in their content area.

There has been a great deal of discussion in recent years about the knowledge base for science teacher education. Given the critical role of language in science learning, it seems that developing a conscious awareness among science teachers of the complex workings of the linguistic technology in construing scientific knowledge, beliefs, and worldviews should be a desirable and necessary goal for science education reform. With such explicit knowledge and understanding, science teachers will be in a better position to apprentice their students to "scientific" ways of reading, writing, thinking, and reasoning. As Wellington and Osborne (2001, p. 138) have eloquently stated,

> As teachers of science, . . . our primary skills lie not in our ability to do science, or showing children how to do science, but in our ability to *interpret* and convey a complex and fascinating subject. We are, primarily, raconteurs of science, knowledge intermediaries between the scientific canon and its new acolytes. Such an emphasis means that we must give prominence to the means and modes of representing scientific ideas, and explicitly to the teaching of *how to read, how to write and how to talk* science. (emphasis original)

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