Volume 2, 13-32 2004

Scientific Language

*Monnipha Gardner**

Abstract

Since scientists are required to have a method of efficient and effective communication when speaking or writing, a specialist language has been developed, known as "scientific language." This specialty language, which is essential for scientists can also prove to be severely limiting, when trying to be utilised by non-scientists. When a language becomes more specialised, it also becomes more difficult to recognise and use by those who are not familiar with that particular branch of science and the language and idioms used by the scientists. This style of writing is most commonly seen in articles and publications by professional scientists, but also frequently occurs in research articles found within the school system. This article analyses features of scientific language at different levels: word, sentence, paragraph, and passage.

Introduction

The language of science has been recognised as a special variety of a language for its distinguishable style (Halliday & Martin, 1993, p. 10). In order to make communication between themselves easier and more effective, scientists have developed their specialist language style, which can limit the access enjoyed by outsiders (Crystal, 1987). The scientific style is an effective tool for specialist communication, but it

---

* Thammasat University Language Institute

can be a barrier to access for those who are outside the community which produces it. The more specialised the common interest, the greater will be the difficulty in obtaining access to the style. Although the style is most obvious in the writings of professional scientists, it is recognisable in a range of documents from research articles through secondary school texts to books written for upper primary classes (O'Toole, 1997).

The scientific language has been recognised for its difficulty and complexity as well as for noticeable reading difficulty experienced by students from a range of language backgrounds. Scientific texts are found to be difficult to read because "they are written in 'scientific language', a 'jargon' which has the effect of making the learner feel excluded and alienated from the subject matter" (Halliday, 1990/1993, p. 69). Scientific English presents special problems of its own, and the problems seem to be much the same for both students who study English as a second or foreign language and those whose English is the mother tongue. It seems that students' difficulty with scientific language is becoming more widely recognised around the world and also at different levels of education as shown in a number of studies (e.g., Barba, 1995; Gardner, 1971, 1974, 1976, 1980; Lynch, 1980, 1996; Lynch, Benjamin, Chapman, Holmes, McCaman, Smith, & Symons, 1979; O'Toole, 1996, 1997; Peacock, 1995; Rosenthal, 1996; Shaw & Dybdahl, 1996; and Zoll, n.d.).

Previous Analyses of Scientific Language

Various analyses to identify and describe characteristic features of scientific English have been made. Some focused on words and sentences, or lexis and syntax whereas others on the discourse features of the scientific style.

Early attempts to a systematic description of the language of science were to count the occurrence of particular language features in samples of science texts. For example, Barber's (1962/1985) statistical description or frequency analysis of scientific language was based on three short texts: a 7,500-word excerpt taken from an engineering textbook (published 1938), a 6,300-word excerpt taken from a biochemistry research paper (published 1947), and a 9,600-word excerpt taken from an undergraduate astronomy textbook (published 1945). Barber analysed his excerpts in terms of two main parts: sentence structure (including verb forms) and vocabulary. He discovered that the average sentence length of his passages was 27.6 words and the modal length was 16-20 words. The sentence structure in his sample was found to be quite simple: 71% of sentences had only one main clause (only 3.4% had more than two main clauses) and 54% had no subordinate clauses (only 6.9% had more than two subordinate clauses). Further analysis of subordinate clauses revealed that adjective clauses were most frequent (39%), followed by adverb clauses of time (20%) and condition (12%), noun clauses, adverb clauses of result, and adverb clauses of degree, respectively. Analysis of the verb forms in his sample indicated that 61% were finite verbs, and 39% non-finites (infinitives, past participles, -ing forms). The present simple was by far the most common verb tense: 64% of verbs in his text sample were in the present simple active and 25% were in the present simple passive. He noted that the progressive forms are of very small importance since only the present progressive active represented only 0.6%, and modal auxiliaries (especially 'can' and 'may') were frequent. In addition, he drew attention to the use of '-ing' forms at the head of attributive phrases (where they act as part of a compound adjective), as well as at the head of noun phrases. Barber also pointed out the use of distinctive vocabulary of science and commented that some words were more common than others within a range of science texts.

Barber's work provided useful statistical information for the teachers of scientific English to justify the difference between 'Scientific English' and 'General English' apart from its use of specialist vocabulary. Further, it provided evidence for generalisations about a variety, type or style of the language and also served as a model for further work on frequency analysis (Swales, 1985, p. 1). However, his approach was severely criticised for being unable to "reveal the communicative character of what was written" or "deal with discourse" (Widdowson, 1979, p. 56).

Different results were reported by Higgins (1967/1985). In his analysis of a sample of scientific English from an undergraduate chemistry course book used in Thailand, he noted that passive verb forms were slightly more common than active ones, and that the impersonal passive structure with 'it' appeared frequently. The most common modal verbs were 'may' and 'should', with the latter occurring very often as part of passive expressions in instructions. 'If' clauses were also found. The simple present and present perfect tenses were very common whereas the progressive tense was rarely used. The difference between Barber's analysis and that provided by Higgins can be viewed as variations within the scientific style and between the text samples used by the two analysts (O'Toole, 1997). Further, Higgins also recognised the importance of words which might not seem particularly technical but were frequently used in technical writings and caused difficulty. He then prepared a list of what he called 'frame' words which were often misused by Thai science students. Higgins' findings were used as a guideline for the preparation of his grammar syllabus as he stated, "we gave prominence to the structures that I had noted in the textbook" (Higgins, 1967/1985, p. 32).

A similar linguistic analysis was carried out by Ewer and Latorre (1967). They compared the language which was characteristic of science text with that normally covered in general courses of English as a foreign language, and emphasised wide variations in lexis between general English and scientific English. In their study of a corpus of over three million words with a range of genres, including professional papers and monographs, advanced and undergraduate textbooks, specialised journals, and semi-popularisations, they found that the science writing in their sample was characterised by '-ing' forms replacing relative expressions, infinitive verb forms substituting for longer phrases, words whose meaning changes with part of speech, use of affixes to modify word meaning and function, and extensive use of qualifying words and phrases. However, these features were "not presented and exercised in any of the courses" (Ewer & Hugh-Davies, 1971-2/1985, p. 48). The following features were essential to basic scientific English but dealt with inadequately in general English courses: compound nouns, passives, conditionals, modal auxiliaries, cause-and-effect constructions, word with similar form but different functions, past participles, and prepositional (two-part) verbs.

Another detailed analysis of the grammar of scientific English by Huddleston, Hudson, Winter, & Henrici (1968) drew on the early systemic functional linguistics developed by M.A.K. Halliday. This descriptive study was based on a corpus of some 135,000 words of written scientific

English drawn from 27 texts of slightly over 5,000 words each. The texts were taken from nine specialist journals, nine undergraduate science textbooks, and nine works of popular science addressed to the layman. The content covered by the first two categories of texts came from the fields of biology, chemistry, and physics. The analysis indicated that the level of expertise of the audience for whom a text was written had more impact upon its language features than did the science discipline which defined its field. The language which was characteristic of each group appeared to differ somewhat. For example, common features of the specialist journals were passive voice (to stress the objectivity of their research), the simple past tense, and a relative lack of grammatical coherence. The common features of the popular science works included active voice, the present perfect and present progressive tenses, and infinitives used as classifying clauses. Among the three groups, the specialist journals had the most simple sentences, the undergraduate textbooks had the most complexes (coordinative and subordinative combined), and the popular science works the most embedded clauses. Differences between the three subject disciplines were, for example, biological texts had more time adjuncts and a high proportion of intransitives, chemistry texts used a high number of circumstantial adjuncts and of instruments as well as passive voice, and physics texts had a high proportion of where-clauses and if-clauses. In addition, the analysis also drew attention to characteristic patterns of mood and attribution within simplex clauses, as well as comparatives, modal auxiliaries, verb structure, cohesive structures and thematic organization. The systemic approach to grammar takes seriously the purposes of language use and treats the function of words as more important than their formal classification.

The most comprehensive survey of the English of Australian high school textbooks (Taylor, 1979) involved the analysis of approximately 700,000 words of text drawn from 18 secondary school textbooks, including four junior science texts. Taylor's analysis indicated that there were broad similarities between the scientific style at the undergraduate and secondary school levels. Of all the subjects under investigation, science texts had the highest number of modal verb forms (2,597 occurrences as compared to 1,270 in history and 251 in commerce) (Taylor, 1979, p. 59). The science sample had the highest incidence of passive voice.

Twenty percent of verbs in the science books were in the passive, compared to 11% in social studies (Taylor, 1979, p. 87). His tense analysis echoed that of Barber and Huddleston, indicating that secondary science text is very high in its use of the simple present tense, above average for the modal present (as in 'may react'), and high in non-finite forms (Taylor, 1979, pp. 143-144). Conditionals or 'if' constructions were pointed out as being of potential difficulty in science books with 332 occurrences in the science corpus compared to only 67 in the history (Taylor, 1979, pp. 232-233). It was noted that secondary science text favored conditioning clauses, complex interruption patterns, modal verbs, abstract nouns and verbs, consistent sentence structures, cohesive markers, passive voice, process clauses, present tense, which-clauses, and technical vocabulary (Taylor, 1979).

Unlike the word- and sentence-based analyses discussed above, Trimble and his colleagues (Trimble, 1985) focused their attention on the discourse features of the scientific style, that is, on its paragraphs and passages. They were interested in the purposes of scientists in writing English, as well as the rhetorical devices the writers used to achieve their purposes. Trimble (1985) noted that scientific discourse mainly used the five specific rhetorical functions of definition, classification, description, instructions and visual-verbal relationships. He also listed the most frequently used rhetorical techniques, which served to bind together the information in a science text, as the natural patterns of time order, space order, and causality and result, as well as the logical patterns of causality and result, order of importance, comparison and contrast, analogy, exemplification, and illustration. It was also held that the language of science was particular not only in its content but also in its rhetoric, and that the sequencing of the items in a piece of written discourse, as well as the expression of the kinds of relationships that existed between these items, was particular and limited. Only a limited number of rhetorical functions were, therefore, employed.

Trimble and his colleagues involved themselves not only in identifying rhetorical functions and their sequencing in scientific texts, but also in analysing the forms of their linguistic realisation, particularly the verb forms. The studies which showed that there is a special language to scientific discourse included those by Selinker, Trimble, and Vroman (1972), who investigated passive-stative distinctions in the rhetoric of descriptions and instructions; Lackstrom (1978), who researched the use of modals in technical discourse, particularly their non-standard use in the rhetoric of instructions; Lackstrom, Selinker, and Trimble (1972/1985), who emphasised rhetorical considerations as determining grammatical choices and analysed the writer's rhetorical choice of verb tense in referring to previous research; and Trimble (1985), who analysed the non-temporal use of tense in the rhetoric of description and the rhetoric of tense choices in text accompanying a visual. This body of research, therefore, contends that written scientific discourse is rhetorically distinct from other forms of English and that there are grammatical repercussions to this distinctiveness.

It can be seen that, in time, the analysis of scientific language changed from traditional studies, which were mainly concerned with statistical descriptions of surface grammatical features (lexical and syntactic characteristics) of the type undertaken by Barber and others and also widely criticised as being conceptually inadequate and merely quantitative (Widdowson, 1975) as well as having "descriptive validity but little explanatory force" (Swales, 1985, p. 59), into discourse studies of a more communicative orientation. These research studies have provided evidence that scientific English is describable and capable of explanation.

Level-based Model of Scientific Language Analysis

This description of scientific English in the present study will be structured according to a level-based model of language analysis. The features which characterise the scientific language can be said to operate at four main levels: word, sentence, paragraph, and passage levels (O'Toole, 1997).

Word Level Features

Words appear to be the most obvious feature of the scientific style of English. Both technical and non-technical terms, which operate at the word level, were proved to cause difficulties to the comprehension of native speakers of English as well as second language learners as documented by Board of Studies (1991, 1994), Gardner (1971, 1972, 1974), Lynch et al. (1979), O'Toole, (1997), and Washington Assessment of Student Learning (2002). According to Cheong (1976, p. 7), technical words may prove easier for the students to grasp than non-technical words. This is because learning the meanings of such words as carbohydrate and molecule is "an automatic consequence of studying the discipline which uses them" and they are often explained as they are introduced by science teachers whereas non-technical words (such as 'valid') are rarely explained.

Specialised or technical vocabulary is the most obvious feature of the scientific style of English (Mayher & Brause, 1983). It has been claimed that the problem lay in the "ponderous style of textbook science" (Lemke, 1982, p. 263.) rather than in something which students lack. Contrary to the commonly held notion that technicality functions to obscure communication, impress listeners and restrict access to a field, the major function of technicality is to enable the "setting up of field-specific taxonomies" (Wignell, Martin, & Eggins, 1989/1993, p. 162). That is, technicality has a field-creating function. It is the resource a discipline uses to name and then order its phenomena in a way which is distinctive to its areas of activity. Thus, through the use of technicality, science establishes the inventory of what it can talk about, and the terms in which it can talk about them.

According to Wignell et al. (1989/1993, pp. 145-146), technical terms may be derived in a number of ways.

a. A technical term may be a single nominal or thing, such as herbivores and consumers. These types of technical terms tend to be the names for physical or living objects, and also tend to be things for which nontechnical taxonomies exist, although, less delicate ones.
b. A technical term may consist of a nominal group compound (a Classifier followed by a Thing). These compounds tend to be ones that are familiar, but appear descriptive rather than classificatory in the nontechnical language, such as physical environment, raw materials, and water vapour.
c. Another nominal group compound (a Classifier followed by a Thing) may be derived from what is called 'implication

sequences' (see Wignell et al., 1989/1993, pp. 156-161 for discussion of implication sequences). These sequences are the way in which the resources of the clause complex are used to posit causal relations between phenomena, such as relief rainfall and frontal rainfall.

d. A technical term may be derived through nominalisation; that is, turning happenings into things which can be technicalised, such as condensation and transpiration.
e. A Classifier in a technical nominal group compound (in a Classifier followed by a Thing structure) is a nominalisation representing the agent from an implication sequence, such as convection currents.
f. Processes are also used as technical verbs and always have a corresponding nominalised form so that they can be treated as things in the text, such as condenses and evaporates.

Technical words can be classified into two subtypes: concept words (such as 'mass', 'gas', 'mixture', 'atom', and 'electron'), and process words (Lynch, 1980; Lynch et al., 1979). In their studies, the recognition of concept words, which form part of the conceptual foundations of the knowledge of science, was found to be necessary for comprehension although not sufficient for it. Also, student control of concept definitions increased with level of schooling. Process words, or fundamental technical process labels such as 'melting', 'condensing', 'diffusion', 'solution', 'evaporating', and 'precipitate', appeared to be more difficult than concept words. They clearly stated that both concept and process words were "key pieces in the verbalisation and communication of scientific knowledge. If such terms are not recognised as simple verbal descriptions then they are unlikely to be understood" (Lynch, 1980, p. 79).

However, it was noted by Halliday (1990/1993) that technical terms are not, in themselves, difficult to master, and that students are not particularly troubled or worried by them. Technical terms are usually given importance by teachers because vocabulary is much more obvious and easier to talk about than grammar.

> The problems with technical terminology usually arise not from the technical terms themselves but from the

> complex relationships they have with one another. Technical terms cannot be defined in isolation; each one has to be understood as part of a larger framework, and each one is defined by reference to all the others (Halliday, 1990/1993, p. 71).

Apart from technical words, non-technical words, which are less common outside science classes or used with different meanings in science contexts, are also characteristic of scientific English (O'Toole, 1997, p. 18). These words contribute to student difficulty because they are unlikely to be directly taught in science classes. The findings of studies in various countries such as Australia (Gardner, 1972, 1974), Britain (Cassels & Johnstone, 1980), Papua New Guinea (Gardner, 1971), and the Philippines (Gardner, 1976, 1980) indicated a common problem and a consistent pattern of student difficulty with non-technical words although the words making up the lists in these studies were not identical. For example, non-technical words which caused difficulty for junior secondary students in Victoria were such as average, concept, consume, descendent, effect, factor, initial, omit, percentage, rate, relative, revise, standard, topic, and valid (Gardner, 1974, pp. 66-69). Misunderstandings of words like these could affect the ease with which students access science text and successfully complete tasks in school science.

The language of science is not only distinguished by its words but also by a range of other features, as noted by Halliday (1990/1993, p. 71) that the difficulty of scientific writing lies more with the grammar than with the vocabulary.

Sentence Level Features

Sentence level features of the language of science are less obvious than the word level features described above. This section will review studies which have looked at the sentence level features in scientific contexts which pose student difficulty

A study based in a cluster of eight schools in Sydney's inner-western suburbs (Carosi & Groundwater-Smith, 1981) identified particular areas of difficulty for secondary science students as follows: adverbs (of frequency, sequence, consequence, and quality), syllogism, mass/unit determiners, conditional tense and passive voice, word order, pronouns (relative and possessive), and sequential phrases. The second language learners in the cluster schools were reported to have greater difficulty with the following features than their monolingual classmates: mass/unit nouns, verbs (endings, agreement, infinitives, and phrasals), prepositions, comparison (of size and quantity), and the tendency to use double negatives. However, the monolingual students performed less well than their second language classmates regarding homophones (e.g. rain/reign), apostrophes, and subject recognition (Carosi & Groundwater-Smith, 1981, pp. 39-40).

Halliday (1990/1993, pp. 71-84) and University of Louisville (2001) identified areas of difficulties that are characteristics of scientific English as:

(1) interlocking definitions are the ways that defining sentences in scientific English are recursive, defining technical terms by reference to other (often equally unfamiliar) technical terms;
(2) technical taxonomies are established through the use of relational processes and nominal groups, and typically depend on two semantic relationships: superordination ('a is a kind of x') and composition ('b is a part of y');
(3) special expressions are groups of words, often with a precise internal structure, which operate as though they were a single term such as 'solving the open sentence over D';
(4) lexical density refers to the number of lexical items (content words) packed into the grammatical structure, and the lexical density of scientific writing tends to be considerably higher than that of other writing;
(5) syntactic ambiguity is caused by verbal expressions which can be interpreted in different ways such as 'may be reflected (in)', 'are...associated (with)', and 'means', and this results from the transformation of actions (clauses) into objects (nouns);
(6) grammatical metaphor is a substitution of one grammatical class or one grammatical structure by another such as a process turned into a noun (instead of by a verb), a participant turned into a possessive (instead of a noun), and a circumstance into an adjective (instead of an adverb or a prepositional phrase);

(7) markers of objectivity (impersonal constructions or "remote" third person) refers to rhetorical devices intended to persuade readers that the statements have the status of nature "as it really is," unperverted by the distortions of personality, opinion, or observer's bias;
(8) semantic discontinuity refers to the assumption of shared knowledge made by science writers, which leads them to leave steps out of the written account of their reasoning, and the readers are expected to work out for themselves the implications to reach a highly complex conclusion. These semantic discontinuities make science text particularly problematic since such chains of reasoning operate above the sentence level. This leads to the next level of text organization which students find difficult.

Paragraph Level Features

Science paragraphs communicate meanings beyond those found in the sentences of which they are composed. These meanings are conveyed through the way that the sentences relate to each other, and that is communicated by the use of connecting words. Such words form a bridge between sentence and paragraph level features.

Connecting words or logical connectives, which serve to link a phrase, clause, or sentence to another phrase, clause or sentence to indicate the flow of argument within a sentence or paragraph, were found to be more common in senior secondary school and tertiary material than in material for the lower grades (Gardner, 1977a). They can be grouped on the basis of their semantic function. Illative connectives (i.e., consequently, hence, as a result, so, so that, thereby, therefore, and thus), a group of logical connectives, were found to occur relatively more frequently in science text than elsewhere (with an exception of 'so'), as supported by Carroll, Davies, and Richman's (1971) analysis of five million words of samples drawn from various school subject areas. These connectives were reported to cause noticeable difficulty for secondary students. For example, Gardner's (1978) findings indicated that between 60% and 70% of Year 7 students could not successfully indicate the proper use of 'thus', and between 30% and 50% of Year 10 students could still not control it.

In Gardner's (1977b) study, tests of almost 200 different logical connectives were conducted using 1,000 different test items. About half of the items were set in a scientific context while the other half were set in more everyday situations. The findings indicated that substantial numbers of junior high school students in Victoria found difficulty in comprehending many of the words linking propositions in written material. The connectives which 30% to 50% of Year 10 students in the study could correctly interpret included words such as similarly, that is, further, in practise, as to, and respectively. Words which less than 30% of the students could correctly use were conversely, if (logical use), and moreover.

Similar difficulties with logical connectives were found in O'Toole (1985). In his study with 323 secondary school students from both multilingual and monolingual communities, it was found that both groups of students experienced difficulties with features of the language of science. More than 75% of both groups of students had difficulty with the following features: technical vocabulary, non-technical vocabulary, adverb modifiers, temporal connectives, demonstratives, and prepositions. The second language group experienced more difficulties than the English-speaking group did regarding the following features: definite and indefinite articles, conditionals, verb forms, additive connectives, and personal pronouns.

A more recent and thorough research study on difficulties of scientific language for secondary students (O'Toole, 1997) also showed interesting results which can be grouped into three major issues. First, different groups of students (monolingual English-speaking students and students from diverse language backgrounds) experienced different degrees of difficulty with the scientific style of English, with the first group doing better but not by all that much. The most difficulty was experienced by young students from diverse language backgrounds, attending low status schools who were asked to use texts of high Flesch readability grade with no language support in their science classes. Second, although there were common problems, different groups of secondary students experienced different degrees of difficulty with different features of the scientific style. Some features appeared to be more difficult than others for particular groups of students. For example, according to the traditional grammar used to analyse the data, students from lower status schools and from linguistically diverse background had more difficulty with nouns than those from high status schools and from monolingual background. Students exposed to ESL/EFL strategies seemed to have significantly greater difficulty with pronouns and adjectives than those students who received no language development help in science classes at all. Students appeared to have similar difficulty with conjunctions regardless of their heritage language or the status of their school. Based on the semantic/functional (modern) grammar analysis, the monolingual English-speaking group had slightly greater difficulty with technicality than the diverse language background group, and conversely the groups whose teachers used EFL/ESL strategy had less difficulty than might have been expected. Regarding word stacks (or unpunctuated strings of adjectives, and nouns or adverbs acting as adjectives, all qualifying a noun which follows them such as "an automated nozzle brick grinder" or "a 35 megalitre per day demonstration plant"), the English monolingual group experienced more difficulty than the linguistically diverse group, and the group of students whose teachers used EFL/ESL strategy experienced less difficulty than they did with other language features. Students from the diverse language background group and from EFL/ESL strategy had more difficulty with passive voice and cohesion than those from the monolingual group and those who received other types of teaching strategies. Third, although students from all language backgrounds did experience some degree of difficulty, specific features of scientific English caused more trouble for students from some language backgrounds than they did for students from other backgrounds. For example, the monolingual English-speaking group had less difficulty with most of the features of scientific language. However, technicality and word stacks caused noticeable relative difficulty for the monolingual group. Spanish-speaking students had particular trouble with articles and word stacks although they had less than average difficulty with prepositions. Italian-speaking students had trouble with the use of the articles in scientific English. They had more difficulty with technicality and passive constructions but they also had more trouble with verbs in general. Vietnamese-speaking students experienced greater than average difficulty in all of the features of the scientific style except prepositions and grammatical metaphor.

Passage Level Features

The last category of characteristic features of scientific English operates on a passage level. Students' difficulties with passage level format conventions were reported in Chandler and Sweller (1992). Their work with university students was focused on the practical report format, which is merely the most obvious of the conventional formats which define science passages (O'Toole, 1997). The experiment compared the communicative effectiveness (as measured by the successful student completion of comprehension questions) of the conventional structure of reports of experiments and an integrated, more narrative-like structure. The findings indicated the superiority of the latter. The university students using the integrated form performed significantly better than those using the traditional format. This was because the integrated form put related information together while the conventional report was sequenced into the traditional method/results/discussion sections and thus split attention between sets of textual information rather than between text and graphics. When reading the conventional format, the readers have to "mentally integrate the information from two or more sections before deriving meaning from the material" (Chandler & Sweller, 1992, p. 239). Conventional practical reports, therefore, do not seem the most effective way of communicating information and may be a factor in student difficulty.

Summary

The characteristic features of the scientific style of English discussed above indicate that they are not arbitrary. They are functional and "evolved to meet the needs of scientific method and of scientific argument and theory" (Halliday, 1990/1993, p. 84). They serve the expert in the field but at the same time cause difficulty to the novice. A wide range of students, both native speakers of English and second language learners, experience difficulty with features of the specialist style characteristic of science at all four levels. In mastering scientific concepts and principles, students have to master these difficulties. Thus, it can be said that learning science is the same thing as learning the language of science (Halliday, 1990/1993).

References

Barba, R. H. (1995). *Science in the multicultural classroom: A guide to teaching and learning.* Boston: Allyn and Bacon.

Barber, C. L. (1985). Some measurable characteristics of modern scientific prose. In J. M. Swales (Ed.), *Episodes in ESP: A source and reference book on the development of English for science and technology* (pp. 3-14). Oxford: Pergamon Press. (Reprinted from *Contributions to English syntax and phonology,* 1962, Stockholm: Almquist and Wiksell).

Board of Studies. (1991). *Chemistry 1990 Higher School Certificate examination report.* North Sydney: New South Wales Board of Studies.

Board of Studies. (1994). *Chemistry 1993 Higher School Certificate examination report.* North Sydney: New South Wales Board of Studies.

Carosi, P., & Groundwater-Smith, S. (1981). *Science is English, too!: A Schools Commission funded augmented evaluation* (Project Evaluation). Sydney: Commonwealth Schools Commission.

Carroll, J. B., Davies, P., & Richman, B. (1971). *Word frequency book.* Boston: Houghton Mifflin.

Cassels, J. R. T., & Johnstone, A. H. (1980). *Understanding of non-technical words in science.* London: Royal Society of Chemistry.

Chandler, P., & Sweller, J. (1992). The split-attention effect as a factor in the design of instruction. *British Journal of Educational Psychology, 62,* 233-246.

Cheong, L. K. (1976). Trends in the linguistic study of English for science and technology. In J. C. Richards (Ed.), *Teaching English for science and technology.* Selected papers from the RELC Seminar on The Teaching and Learning of English for Scientific and Technological Purposes in Southeast Asia (pp. 3-17). Singapore: Singapore University Press for SEAMEO Regional English Language Centre.

Crystal, D. (1987). *The Cambridge encyclopedia of language.* Cambridge: Cambridge University Press.

Ewer, J. R., & Hughes-Davies, E. (1985). Further notes on developing an English programme for students of science and technology. In J. M. Swales (Ed.), *Episodes in ESP: A source and reference book on the development of English for science and technology* (pp. 47-55). Oxford: Pergamon Press. (Reprinted from *English Language Teaching, 26*(1&3), 1971-1972).

Ewer, J. R., & Latorre, G. (1967). Preparing an English course for students of science. *English Language Teaching, 21*(3), 221-229.

Gardner, P. L. (1971). *Project SWNG: Scientific Words New Guinea.* Melbourne: Territory of Papua and New Guinea Department of Education.

Gardner, P. L. (1972). *Words in science.* Melbourne: Australian Science Education Project.

Gardner, P. L. (1974). Language difficulties of science students. *Australian Science Teachers Journal, 20*(1), 63-76.

Gardner, P. L. (1976). *Project WISP: Words in Science-Philippines* (Colombo Plan Research). Manila: University of the Philippines Science Education Centre.

Gardner, P. L. (1977a). *Logical connectives in science.* Report to the Education Research and Development Committee.

Gardner, P. L. (1977b). Logical connectives in science: A summary of the findings. *Research in Science Education,* 7, 9-24.

Gardner, P. L. (1978). Difficulties with illative connectives in science amongst secondary students. *Australian Science Teachers' Journal, 24*(3), 23-30.

Gardner, P. L. (1980). Difficulties with non-technical scientific vocabulary amongst secondary school students in the Philippines. *Australian Science Teachers Journal, 26*(2), 82-90.

Halliday, M. A. K. (1993). Some grammatical problems in scientific English. In M. A. K. Halliday & J. R. Martin (Eds.), *Writing science: Literacy and discursive power* (pp. 69-85). London: The Falmer Press. (Reprinted from *Australian Review of Applied Linguistics Series S, 6,* pp. 13-37, 1990).

Halliday, M. A. K., & Martin, J. R. (Eds.). (1993). *Writing science: Literacy and discursive power.* London: The Falmer Press.

Higgins, J. J. (1967). Hard facts: Notes on teaching English to science students. In J. M. Swales (Ed.), *Episodes in ESP: A source and* *reference book on the development of English for science and technology* (pp. 30-34). Oxford: Pergamon Press. (Reprinted from *English Language Teaching, 21*(1), 1967).

Huddleston, R. D., Hudson, R. A., Winter, E. O., & Henrici, A. (1968). *Sentence and clause in scientific English.* London: Communication Research Centre, Department of General Linguistics, University College London.

Lackstrom, J. E. (1978). Teaching modals in EST discourse. In M.Todd Trimble, L. Trimble, & K. Drobnic (Eds.), *English for specific purposes: Science and technology.* Corvallis, OR: Oregon State University Press.

Lackstrom, J. E., Selinker, L., & Trimble, L. P. (1985). Grammar and technical English. In J. M. Swales (Ed.), *Episodes in ESP: A source and reference book on the development of English for science and technology* (pp. 60-66). Oxford: Pergamon Press. (Reprinted from *English Teaching Forum, 10*(5), 1972).

Lemke, J. L. (1982). Talking physics. *Physics Education, 17*, 263-267.

Lynch, P. P. (1980). The language of science and the Tasmanian high school student: Part 4 the recognition of process definitions. *Australian Science Teachers Journal, 26*(1), 75-79.

Lynch, P. P. (1996). Students' alternative frameworks: Linguistic and cultural interpretations based on a study of a western-tribal continuum. *International Journal of Science Education, 18*(3), 321-332.

Lynch, P. P., Benjamin, P., Chapman, T., Holmes, R., McCaman, R., Smith, A., & Symons, R. (1979). Scientific language and the high school child. *Journal of Research in Science Teaching, 16*(4), 351-357.

Mayher, J. S., & Brause, R.S. (1983). Learning through teaching: Teaching and learning vocabulary. *Language Arts, 60,* 1008-1016.

O'Toole, J. M. (1985). Science exercises: A summary of the evaluation. *Language Links, 11,* 22-29.

O'Toole, J. M. (1996). Science, schools, children and books: Exploring the classroom interface between science and language. *Studies in Science Education, 28,* 113-143.

O'Toole, J. M. (1997). *Difficulties of scientific language for secondary school students.* Unpublished doctoral dissertation, University of New South Wales, Sydney.

Peacock, A. (1995). An agenda for research on text material in primary science for second language learners of English in developing countries. *Journal of Multilingual and Multicultural Development, 16*(5), 389-401.

Rosenthal, J. W. (1996). *Teaching science to language minority students.* Avon: Multilingual Matters.

Selinker, L., Trimble, L., & Vroman, R. (1972). *Working papers in English for science and technology.* College of Engineering, University of Washington.

Shaw D. G., & Dybdahl, C. S. (1996). *Integrating science and the language arts: A sourcebook for K-6 teachers.* Boston: Allyn and Bacon.

Swales, J. M. (Ed.). (1985). *Episodes in ESP: A source and reference book on the development of English for science and technology.* Oxford: Pergamon Press.

Taylor, C. V. (1979). *The English of high school textbooks* (Education Research and Development Committee [ERDC] Report No. 18). Canberra: Australian Government Publishing Service.

Trimble, L. P. (1985). *English for science and technology: A discourse approach.* Cambridge: Cambridge University Press.

University of Louisville. (2001). *Characteristics of "high science" writing.* Retrieved April 5, 2004, from http://www.louisville.edu/a-s/english/dale/105/99f/101399.htm

Washington Assessment of Student Learning. (2002). *Science: General characteristics and scientific vocabulary.* Retrieved April 5, 2004, from http://www.tacoma.k12.wa.us/Schools/Curriculum/ospiresources/Science2004/Gr5-10ScienceVocab.pdf

Widdowson, H. G. (1975). EST in theory and practice. In English Teaching Information Centre, British Council, *English for academic study with special reference to science and technology: Problems and perspectives* (an ETIC occasional paper). London: British Council.

Widdowson, H. G. (1979). *Explorations in applied linguistics.* Oxford: Oxford University Press.

Wignell, P., Martin, J. R., & Eggins, S. (1993). The discourse of geography: Ordering and explaining the experiential world. In M. A. K. Halliday & J. R. Martin (Eds.), *Writing science: Literacy and discursive power* (pp. 136-165). London: The Falmer Press. (Reprinted from *Linguistics and Education, 1* (4), pp. 359-391, 1989).

Zoll, M. (n.d.). *Distinguishing characteristics of medical writing.* Retrieved April 5, 2004, from http://www.stc.org/confproceed/1997/PDFs/0196.PDF