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ABSTRACT

With traditional science textbooks still dominating the market, it is projected that the use of print material and related reading skills will persist as the prime method of science instruction. The need to research reading-science issues exists. This paper attempts to define the task or desired outcomes of research in reading-science dimensions. Areas developed in this paper include: (1) science reading and comprehension; (2) theories of the reading process (illustrated by models); (3) research in science reading (presented by grade level, subject matter, and curricular programs); (4) reading comprehension and science achievement (emphasizing text structure); and (5) research trends and issues. Findings are also presented on readability research on science materials. It is suggested that science educators need to research reading-science issues to develop theories, textual materials, skills and classroom strategies related to effective reading and reading comprehension. An extensive reference list follows the report. (ML)

READING, UNDERSTANDING, REMEMBERING AND USING INFORMATION IN WRITTEN SCIENCE MATERIALS

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INTRODUCTION

Comprehension, understanding what is said, shown or written, should be a major concern of science educators. Generally reading and reading comprehension have been neglected by science educators for nearly 30 years. The post-Sputnik era of science education de-emphasized reading about science in favor of doing science. Hands-on, concrete, student-centered science experience is a justifiable position for teaching and learning science, but one held by a small minority of teachers and practiced by an even smaller percentage. Even during the new science heydays of the late 1960s and early 1970s, only a small percentage of teachers utilized concrete experiences. Traditional science textbooks still dominated the market. Weidler (1984) indicated the degree of neglect when she stated "articles concerning research and theory in the combined area of reading and science are surprisingly scanty in number" (p. 54).

Public demands for more rigorous science curricula, more concentrated science textbooks, CAI software requiring language skills, education spending restraint, lack of properly educated science teachers and large class sizes will likely increase the use of print material and related reading skills as the prime method of science instruction. This likelihood dictates that science educators need to research reading-science issues to develop theories, textual materials, skills and classroom strategies related to effective science reading and reading comprehension. Literature from educational psychology, reading and science education indicates an evolved research focus from characteristics of the text, to bottom-up cognitive skills of the reader, to top-down metacognitic skills of the reader to currently an interactive constructive cognitive-metacognitive process. Chall (1983) pointed out that instruction in reading needs to progress from the learning-to-read stage to the reading-to-learn stage. Much effort has been directed at exploring the earlier stage of developmental reading skills and processes. Now Learning How to Learn from Reading (Brown, 1982) must blend content and reading expertise and be assigned a higher priority.

This paper attempts to define the task or desired outcome, describe related contemporary theories, summarize the reading-science research and predict potential and fruitful research issues and techniques.

THE TASK: SCIENCE READING AND COMPREHENDING

Story Grammars

Scientific and technological prose are uniquely different from traditional fiction. Mandler and Johnson (1977) suggest that children's stories, mystery stories and other forms of fiction follow a story grammar which has a distinct and predictable internal structure. A standard story grammar involves main characters, protagonists, goals and obstacles. Bruce and Newman (1978) point out that more complex story grammars include

-iations of main characters, competition, conflict and sharing. Authors use illustrations to provide graphic clues about characters, goals and obstacles (Brown, 1982). In mystery stories, illustrations may be used to provide false clues to more fully establish the mystery. Johnson and Mandler (1980) provide a set of descriptive rules for story grammars that involve content words, propositions, levels of propositions, categories of propositions, and episodes of categories. Content words are specific vocabulary that convey the message of the story, such as verbs, nouns, verb phrases and noun phrases. Propositions are predicates, normally a verb and agreements of the verb. Levels of propositions are proposition groups identified by mature readers as being the most important (Level 1), second most important (Level 2), and so on. Story grammars have six categories of propositions clustered into the setting, beginning, reaction, attempt, outcome, and ending. Categories are connected by three semantic relationships: and, then, and cause. Story grammar contains at least one episodic cluster of categories related by and-then relationships.

Research indicates that readers rely on story grammar to process, to recall and to comprehend a story (Rumelhart, 1977; Mandler & Johnson, 1977; Thorndyke, 1977; Stein & Glenn, 1979). Story grammars appear to parallel the reader's schema, which is a composite of real-life experience and experience with prose. Immature readers generally recall propositions in the same ordered levels as mature readers (Thorndyke, 1977; Kintsch & van Dijk, 1978; Pronger, Johnson & Yore, 1985). Young readers recall setting, beginning and outcome categories most often and reaction category least often (Mandler & Johnson, 1977). Episodes are recalled in order of the story. Pronger, Johnson and Yore (1985) suggest that repeated hearings of a story results in assimilation of additional propositions into the listener's schema. They found mixed indications that listeners restructured or refocused their schema to accommodate new or discrepant ideas and noted no significant increase in comprehension. According to Brown (1982), "the more the readers know about such standard story [grammars], the easier it will be to read and understand stories" (p. 44).

Science Prose

Science writings generally attempt to describe and explain patterns of events not part of normal daily experience. A description and explanation of DNA must rely on related concepts, abstractions and tangential experiences to enhance meaning. Unlike many best-selling novels that skillfully and tantilizingly weave love, hate, survival and other common life experiences, science deals with informing the uninformed and unexperienced. Eisenberg (1977) suggests that science language utilizes unique lexicon, syntax, semantics and logic that influence the comprehension of scientific and technological prose. Science lexicon consists of words with singular meanings not commonly used in daily communications. Science prose are semantically and logically expository, which do not parallel natural oral language, are terse and concise, and lack the degree of redundancy found in most fiction. Science syntax utilizes frequent referents, large amounts of anaphora, passive verbs, embedded sentences and nominalization (Weidler, 1984). Scientific prose contain chained sentences, with logical connectives to illustrate cause-effect and if-then relationships of two ideas, propositions or sentences (Gardner, Schafe, Myint-Thein & Walterson, 1976; Cassidy, 1977; Eisenberg, 1977; Gardner, 1980). These logical linkages are prepositional phrases, adjectives, explicit indicators, coordinators, and adverbials. Adverbials establish logical conditions, such as additive adjunct, restrictive adjunct, disjunct and conjunct (Gardner, et al., 1976). Science writings also make frequent use of Latin and Greek root words and combining forms (Piercey, 1976; Cassidy, 1977; Knight & Hargis, 1977). Logic sequences of step-wise instructions or directions are found frequently in science text (Cassidy, 1977; Pikulski & Jones, 1977). Science textual materials contain a high degree of visual materials, such as pictures, diagrams and graphs. Finally, scientific prose have embedded in them unique problems related to mathematics English that has symbols without typical phoneme-grapheme relationships and other than left-right/top-bottom saccadic eye movements (Nolan, 1984).

Brown (1982) suggests that "although not as uniform in structure as stories, expository texts also take predictable forms" (p. 44). Armbruster and Anderson (1981) point out that compare and contrast is a structure that expository text like science prose utilizes. Science text also uses titles, headings, subheadings and topic sentences to identify main ideas. Paragraphs normally develop deductively with the topic sentence containing the main idea followed by subordinate sentences with specific facts and detail. Some attempts have been made to use inductive paragraph development.

Spiro (1980) notes that "the author of an ex[illegible] text ... intends something more than communication. He or she intends knowledge acquisition, growth and integration beyond the confines of text materials and intentions specifically related to that material in isolation" (p. 251). Brown (1982) implies that expert learners realize the purpose of such structures and devices, use them in the reading process, and that this knowledge helps improve comprehension.

Reading Comprehension in Science

Comprehension is synonymous with understanding. But what does it mean to understand something in science? Some researchers seem to suggest that understanding can be derived directly from print (Allington & Strange, 1980). While these authors include some notion of the activity of the reader is the extraction of meaning (they call this "access to meaning in print"), they relate the essential meaning to the text itself.

According to Thelen (1984), comprehension is a process that involves more than decoding. It involves what some refer to as "prior knowledge" (Marshall & Glock, 1978-79), or existing "schemata" (Anderson, 1978; Anderson, Spiro & Anderson, 1978). Prior knowledge and schemata are not themselves linguistic patterns, but rather cognitive structures, which develop through previous experience with the science concepts. Comprehension is the interaction of the new material and the existing cognitive structure within the reader (Ausubel, Novak & Hanesian, 1978). It is a reasoning and thinking process that involves predicting, organizing, analyzing, remembering, and evaluating textual material (Lira, 1980).

The notion of prior knowledge and cognitive structures suggests that comprehension and meaning do not lie outside the reader in the text but a. ɘ internally constructed by generative mechanisms of intelligence. As Goodman (1976) notes, meaning depends as much on the reader as it does on what is being read. In science, what the learner brings to the reading task depends heavily on the amount of direct experience with the concept to be understood. Without prior experiences relevant to the science to be learned, students often end up memorizing materials as a survival tactic (Vachon & Haney, 1983).

The interactive process of reading comprehension suggests that science readers must possess complex patterns, which allow them to read meaning into textual material rather than merely extract meaning from it. This further suggests that reading is not a collection of skills but an organized system by which specific texts trigger structural patterns to form a coherent meaning experience. This systems notion seems indicated by the resistance of reading to component analysis. Reading comprehension seems to be holistic. Thorndyke (1973) and Rosenshine (1980) both showed the collapse of distinct comprehension abilities in the face of factor analysis. One verbal factor called comprehension remains. Any discrete factors have so much interaction with other factors they remain indistinguishable from the system as a whole.

The science classroom presents a unique opportunity for the student to develop cognitive structures in which science textual material can have meaning. Laboratory activities, demonstrations, and models experienced prior to text reading assignments increase the comprehensibility of the text material. Without prior experience or well-formed schemata, reading assignments become exercises in memorization or forgetting.

THEORIES OF THE READING PROCESS

Bottom-Up Model

The bottom-up model of reading assumes the majority of meaning is stored in the textual materials. Successful readers need only decode the words, structures and relationships embedded in the print symbols. Once these secrets are decoded and input into the brain, the reader mentally processes the message to distill concepts and principles that are then stored in memory to be retrieved later. Bottom-up reading focuses on the decoding skills, such as vocabulary, phonetics, phoneme-grapheme associations, meaning from context, use of root words and combining forms, semantics, grammar, syntax, logical connectives, use of analogies, recognizing main ideas, and recognizing supportive details.

Chomsky (1957) and others directed much of their efforts to exploring text-driven models of reading. Their linguistic inquiry focused on patterns of language, rules of syntax and later on semantics. Gough's (1972) model of reading is one of the most recent bottom-up interpretations of reading. Figure 1 summarizes

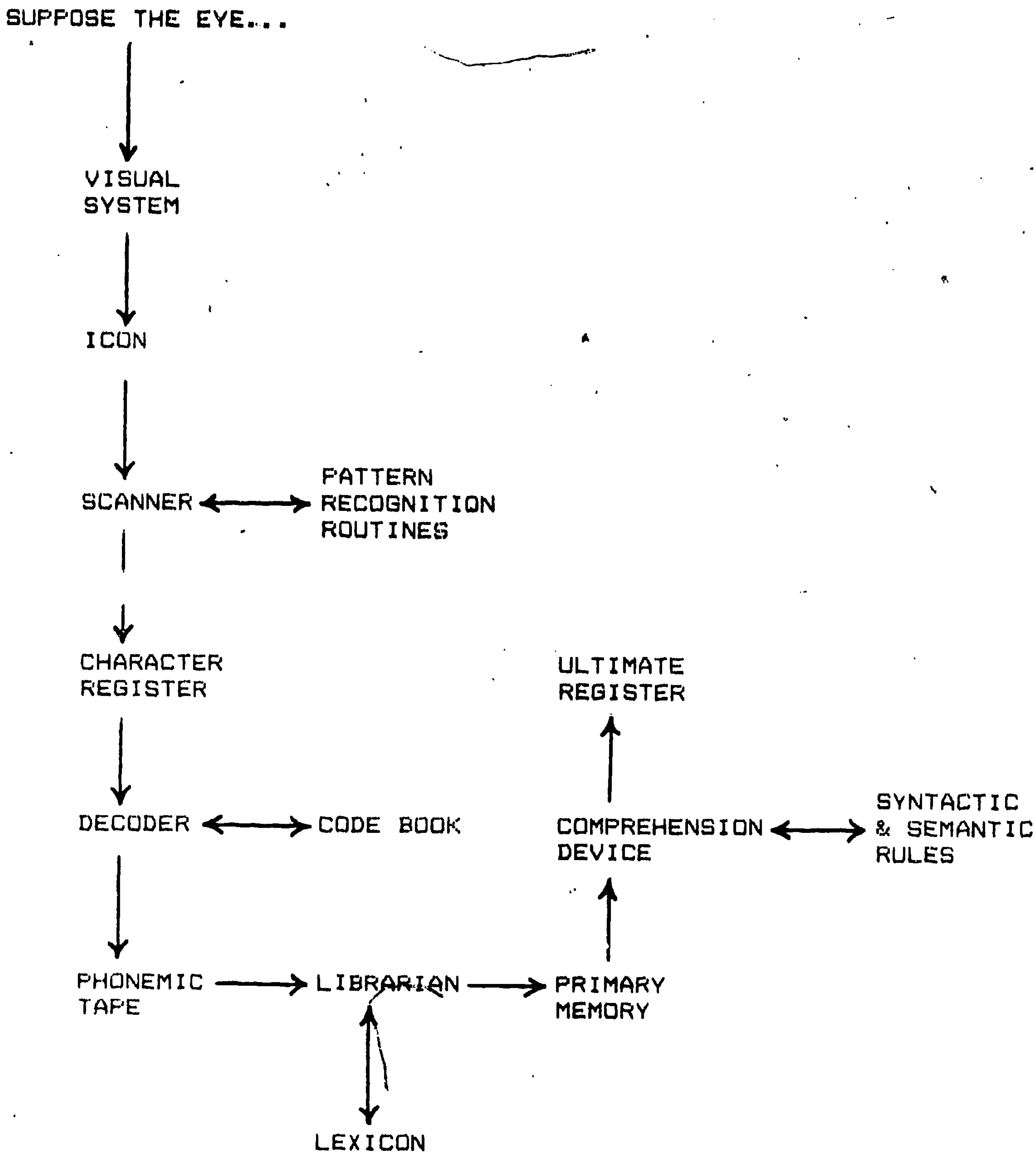

Figure 1. Gough Model of Reading (adapted from Samuels and Kamil (1984, page 193).

the unidirectional text-driven model. Gough synthesized the work on saccadic movements, fixations and regression of the readers' eyes into the iconic representation, part of print in focus, or icon. The reader processes the symbols in the icon rapidly in a letter-by-letter sequence. The reader next searches his lexicon for clusters of letters for meaningful words and related ideas. Samuels and Kamil (1984) suggest that:

> ... primary memory serves as a brief storage system for the comprehension device. Precisely how the comprehension device works is under investigation, but it is assumed that [it] discovers the deep structure of the word strings in primary memory. Once [the comprehension device] succeeds in extracting the deep structure of the word string, the semantic content is moved to the ultimate register (p. 195).

Samuels and Kamil (1984) point out that the early LaBerge and Samuels model was a bottom-up approach that emphasized decoding, attention and comprehension. The LaBerge and Samuels model also attends to visual memory, phonological memory, episodic memory and semantic memory. The revised LaBerge and Samuels (1977) model has added feedback loops that no longer makes it an exclusive bottom-up model. The revisions better explain the role that matching of print information and mentally stored information has on comprehension. Samuels and Kamil (1984) suggest that contextual cues found in textbooks, such as titles and headings, guide the reader's comprehension.

Bottom-up models of reading have influenced most science reading research and instructional practices to date. Science educators have applied readability formulas, modified scientific syntax, controlled vocabulary, sentence length and various other linguistic variables. These results are reported later but they have been less than mind-bending and insightful. Instructional practices and curricular materials have tried to improve readers' ability and skills at decoding, encoding and processing science prose. These attempts have had limited success at improving bottom-up reading and the skills developed are not easily transferred to a new reading situation.

Top-Down Model

The top-down reading process focuses on the metacognitive skills of the reader. What the reader brings to the printed page and what strategies the reader applies are central issues of the top-down reading process. The concept-driven top-down model assumes the reader brings more information to the reading act than the page does (Strange, 1980). Brown (1982) identified two clusters of metacognitive skills involved in the concept-driven reading process, namely, knowledge the reader has about the situation and self-regulating mechanisms used by the reader. Prior knowledge, information processing skills and task identification are metacognitive skills of the first type. Brown (1982) suggest that the second cluster of metacognitive skills includes:

> ... attempts to relate a new problem to similar class of problems and to imbue the unfamiliar

with the familiar, engage in means end analysis to identify effective strategies; checking the outcome of any attempt to solve the problem; planning one's next move; monitoring the effectiveness of any attempted action; testing, revising, and evaluating one's strategies for learning and other strategic activities that facilitate learning (p. 28).

The top-down reading process can be supported by poor readers' inabilities to predict and anticipate upcoming text, to confirm uncertainties or to develop coping strategies for inconsiderate text. Good readers can selectivey ignore illogical print, fixing up inconsistencies by substituting more meaningful ideas and developing a variety of self-regulating operations. Schallert and Kleiman (1979) suggest that teachers can modify textual materials to the readers' level of understanding, activate related knowledge, focus the readers' attention and help readers monitor their comprehension to improved reading comprehension. Baker and Brown (1984) stress the importance of several metacognitive skills, such as the readers' conceptualization of the purpose of the reading task, the awareness of their own activities and the ability to solve problems while reading.

Interactive Constructive Model

As one tries to comprehend the message in many science-related cartoons, one demonstrates that reading may not be a unidirectional process. As the reader decodes the visual and symbolic message, meaning is absent unless prior knowledge or experience is activated. Likewise, prior knowledge stimulates uncertainties and predictions that require additional information from the cartoon. Rystrom's (1977) critical analysis of the text-driven and concept-driven models of reading produced reasons that questioned both theories. Rystrom posits that an exclusive bottom-up model does not explain divergent interpretation of a given text and the top-down model does not explain the mastery of drastically new materials and high degree of agreement between different readers of the same material. Rumelhart (1976) proposed an interactive model that incorporates both unidirectional models. Spiro (1980) suggests that "the interactive product of text and context of various kinds, including linguistic, prior knowledge, situational, attitudinal and task contexts" construct meaning during reading (p. 246). Spiro continues:

> The text is obviously part of the meaning-creating process. However, it must be considered in concert with the contextual settings and the activities of the reader/hearer who, by making an effort after meaning, will attempt to construct a comprehension product that makes sense within his/her individual view of the world.... Discourse is contextually embedded, and the contexts in which it occurs guide extra-textual construction.... Thus there are a variety of contexts: the other neighboring discourses any given one may be embedded in: the peceived task requirements of a given situation; the

situation itself; and the interests, attitudes, and preexisting knowledge of the comprehender (pp. 250-251).

The interactive constructive model utilizes Bartlett's schema theory to explain the interplay of prior knowledge in reading. Pearson and Spiro (1982) describe many of the comprehension successes and failures in terms of schema establishment, schema availability, schema selection and schema maintenance. Pearson and Spiro describe reading comprehension in much the same terms as Piaget's equilibration process. Assimilation becomes the bottom-up phase of reading that fills in voids in pre-existing knowledge or a specific schema. Accommodation occurs after unexpected or discrepant information is encoded into a schema causing disequilibrium or dissonance. Accommodation results in modifications of the selected schema or in selection of a more appropriate schema. Few results indicate overwhelming evidence to support direct relationships between measures of cognitive development and early reading skills (Waller, 1977). Ferrerio and Teberosky (1982) utilized Piagetian research methods to explore early reading and writing behavior. Their unique treatment of language and language-related symbols as objects provides interesting insights into young children's understanding of language and the potential use of equilibration. Gallagher (1979) suggests that reading research consider the global meaning of cognitive development rather than the specific tasks. She contends that reading researchers are sometimes misguided by an over-emphasis on Piaget's logical model and the stages of cognitive development. What is needed is a shift to Piaget's biological model, the dynamics of the mechanisms inherent in equilibration or self-regulation (p. 72). Yore and Ollila (in press) found that cognitive development is related to recognition of concrete and abstract words by early readers.

Likewise, the constructive interactive reading model parallels much of the receptive learning model (Ausubel, Novak & Hanesian, 1978) as shown in Figure 2. Conceptual maps are very similar to reading schema and textual structure analyses outlined by Meyers (1975) and Anderson (1978). It may be that concept maps are effective methods of establishing and maintaining reading schema.

Comparison of Models

Smith (1980) contrasted three different theories of reading and reading comprehension by applying them independently to a familiar nursery rhyme:

Jack and Jill went up the hill
To fetch a pail of water.
Jack fell down and broke his crown
And Jill came tumbling after.

His work suggests that syntax/semantics bottom-up approach leaves the comprehender with a much less vivid representation of the story and far more unanswered questions than does a top-down approach or an interactive constructive approach. The top-down and constructive models of comprehension include more than what is contained in the symbols on the page. The reader's purpose for reading, prior knowledge, attitude and processing skills will also

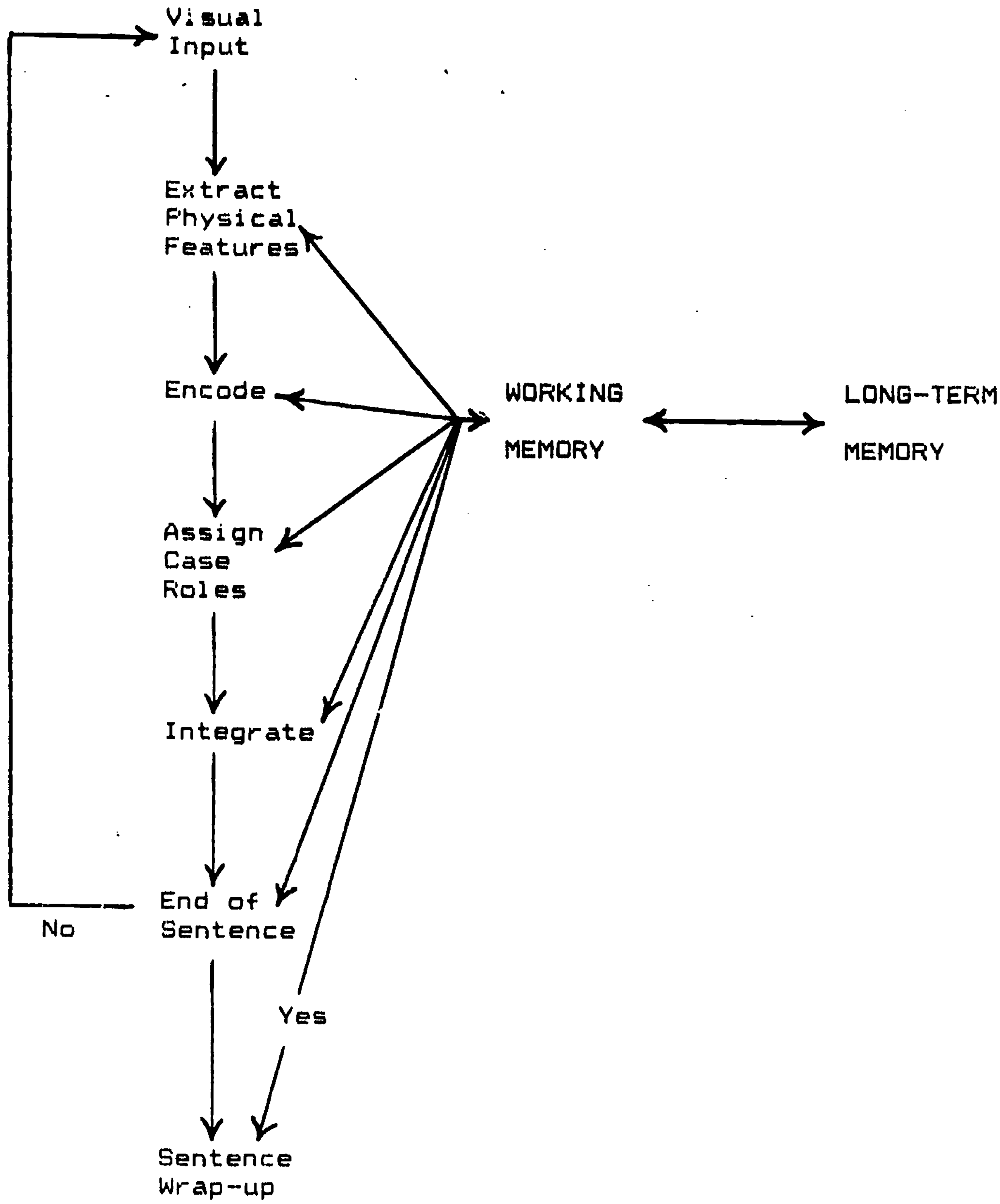

Figure 2. Just and Carpenter's Interactive Model of Reading (adapted from Samuels and Kamil, 1984, p. 214).

influence the representation comprehended from those print symbols. Many of Smith's arguments and comparisons could well be applied to science prose.

Successful readers have a repository of reading skills that allow them to extract ideas from print, process information, seek additional data and construct meaning. Brown (1982) states that "reading for them is an active process of information gathering, evaluating, and hypothesis testing; they know how to extract information from texts, to critically evaluate its importance, its reliability and the evidence that supports" it (p. 49). These readers monitor their understanding, memory and progress automatically.

Less effective readers do not possess these decoding, searching and anticipatory skills, appropriate prior knowledge or understanding of the reading act. According to Brown (1982):

> Reading is not a primary or preferred mode of obtaining information and the task of studying is often interpreted as involving nothing more than passive, sometimes desperate rereading of texts. Such students can be helped to become more active learners via training programs based on awareness and self-control. In order to become expert learners...they must learn about their own cognitive characteristics, their available learning strategies, the demands of various learning tasks, and the inherent structure of the material. They

must tailor their activities to the demands of all these forces in order to become flexible and effective learners (pp. 49-50).

Samuels and Kamil (1984) stated

> Each of the models described has a specific focus, usually different from other models. Gough ... and Rumelhart all concentrate most of the power of their models on word-recognition processes. Within this group, the emphasis is either on strict linear processing (Gough) ... or on interactive processing (Rumelhart) .... The model of Just and Carpenter and that of Kintsch and van Dijk concentrate on comprehension, almost to the exclusion of letter-level processes. This lack of a common focus is the largest impediment to making comparisons among the models.
>
> While each model tends to draw upon conceptualizations of the reading process which have preceded it, it does not follow that the earlier models are no longer useful because each model describes a somewhat different aspect of reading. Thus, each model provides unique information about the reading process not found in the other models....
>
> Finally, we should recognize that our models have gaping holes in them. As we have developed

some sophisticated ideas about how comprehension takes place and how metacognitive strategies are used to facilitate reading, the models have been slow to incorporate this information (pp. 219-220).

RESEARCH IN SCIENCE READING

Readability Research

Readability is an attempt to measure or predict a reader's ability to read textual materials. Martin (1962) recapped the history of readability as being four phases, each with a unique focus. Initially readability studies focused on vocabulary, while the second phase focused on linguistic variables of difficult passages, the third phase explored correlatives between component language and difficult prose, and the fourth phase explored the interactive reading model inherent in the Cloze readability measure. Phases 1 and 2 outlined by Martin appeared to assume a static or bottom-up reading model. Studies during these phases produced estimates of readability that utilized words, syllables, concept load, structures, and sentence length. Word lists of familiar and unfamiliar words were products of the early phases of readability.

The third phase produced a variety of correlation equations that considered sentence length; frequency of unfamiliar words; number of phrases, personal referents, affixed morphemes, polysyllabic words and syllables; percentage of indeterminate clauses and occurrence of technical concepts (Dor·n & Sheard, 1974). Readability formulas generally consider two or more of these structural variables of written language correlated with some measure of reading success (Esralson, 1976). The Lorge (1944), Dale-Chall (1948), Flesch (1948), Spache (1953), Fry (1968 & 1977), and SMOG (McLaughlin, 1969) are examples of readability formulas generated during the third phase that are still popular today.

The fourth phase hallmarked a breakthrough in what researchers defined as reading. An interactive model that utilized text and reader as inseparable and dynamic appeared to guide this phase. Both characteristics of the written text and traits of the involved reader were explored. Bottom-up words, grammar, structures, encoding and decoding were mixed with top-down prior knowledge, information processing and looping. Furthermore, reading success refocused to consider meaning rather just mouthing the word. The inclusion of reading comprehension in readability studies started with the advent of the Cloze procedure (Taylor, 1953). The Cloze procedure attempted to relate text, reading and learning characteristics of "Reading to Learn" rather than just "Learning to Read" (Chall, 1983).

Discussing the specific merits of each of these formulas and procedures would be an overwhelming task and likely best done by the original references mentioned. Holliday (1983a) cautioned science educators about the use of readability formulas as the sole factor influencing textbook decisions. Such data including the Cloze procedure are only starting points to the understanding of content reading demands of science textbooks and comprehension. Early science education researchers suggested that the Lorge, Dale-Chall and Flesch formulas provided comparable reading levels in text materials. Richer (1978) compared several formulas and suggested that similar results from readability formula mean significantly different things.

Various readability formulas have been applied to science textbooks for over thirty years. The results for elementary science, junior high science, biology, chemistry, physics, college and university science and mathematics textbooks are summarized in the following sections. These data are provided to clearly indicate the first steps taken in science reading research.

Elementary Science Studies. Mallinson, Sturm and Patton (1950) explored intermediate (grades 4, 5 and 6) science textbooks and found that these textbooks were somewhat too difficult for students in intermediate grades. They also found that internal reading difficulty of the textbooks did not logically develop from easier beginning sections to more difficult later sections. Burkey (1954) reported that some of the 41 elementary science textbooks explored had readabilities below grade level (7 textooks), within grade level (18 textbooks), to above grade level (16 textbooks). Burkey also found extreme internal variations in readability. Denslow (1961) found grade 1 science textbooks were above grade level. Ottley (1965) found that the discrepancy between readability of science textbooks and reading ability of students decreased between grades 4 and 6.

Newport (1965) found that primary school science textbooks were appropriate for primary school students and intermediate grade science textbooks were appropriate if slight modifications were considered. O'Toole and Bedford (1969) suggested that science terminology was the major factor responsible for inflated readabilities of science textbooks. The addition of science words to Dale's word list decreased science textbook's readabilities from one to two grade levels. Gilbert (1973) supported O'Toole and Bedford's position and added that sentence structure also affected the readability of science textbooks.

More recent studies (Esralson, 1978; Williams & Horne, 1978; Shymansky & Yore, 1979; Yore, 1979a; Yore, 1979b; Yore, 1979c; Yore, 1979d; Orpwood & Souque, 1984) generally confirm that elementary school science textbooks are difficult, that science textbooks do not start with easier sections and develop to more difficult sections, and that science textbooks and science programs have extreme internal variation in readability. Williams and Yore (1985) found that elementary science textbooks' readability varies with content area, that visual layout does not significantly affect readability, and that the gap between science textbook readability and students' reading ability increases between grades 4 and 6.

Junior High School Science Textbooks. Mallinson, Sturm and Mallinson (1954) reported that general, physical and earth science textbooks had sizeable internal variation in readability. General, earth, and physical science textbooks had readabilities beween seventh and tenth grade levels. Kline (1966) found that earth science textbooks had reading levels of one to four grade levels above the intended readers. Kennedy (1974) reported that textbooks associated with the new science curricula had reading levels that were generally more than one grade level above the intended readers and internal variation of less than one grade level. Analysis of ISCS materials indicated that the materials were at or below the grade level intended, were very interesting and that the reading ability of students using the ISCS materials appeared to improve (Conner, 1977). Esralson (1978) found readabilities for laboratory textbooks and associated science readers to be above grade level and extremely high internal variation.

Biology Textbooks. Mallinson, Sturm and Mallinson (1950) reported that the biology textbooks studied had an average reading level of Grade 8 and considerable internal variation. Beldon and Lee (1961) reported only one of five biology textbooks investigated had a readability useful to over 50% of the intended readers. Robinson (1964) found that the BSCS Blue Version had sections with readability between grade 11 and 12, a high introduction rate of scientific terminology (4 science terms per 100 words), and a very high concentration of scientific terminology (7,000 science terms introduced). Lee and Hislop (1968) concluded that average readers would experience difficulty with vocabulary and concepts in all versions of BSCS biology. Holler (1969) reported a sizeable discrepancy between readability reported by the publisher and those measured by the Cloze procedure for BSCS materials. Daugs and Daugs (1974) suggested that writing style was a more critical contributor than scientific vocabulary in BSCS materials.

Chemistry Textbooks. Powers (1924, 1926) and Kitzmiller

(1931) suggested that scientific terminology was the major factor affecting readability of chemistry textbooks. If only required terminology were introduced as absolutely needed and continued to be used for reinforcement, chemistry textbooks would be much more readable (Powers, 1924). Mallinson, Sturm and Mallinson (1952a) concluded that chemistry textbooks were generally too difficult for intended readers, had extreme internal variation and did not parallel logical reading groups between early chapters and later chapters. Beldon and Lee (1962) indicated that the reading level of most chemistry textbooks made them useful to less than half the chemistry students. Powell (1966) found that chemistry textbooks were one to three grade levels above the chemistry students sampled. Powell implied a relation between students' reading ability and chemistry achievement. Esralson (1976) found that the three versions of CHEMS chemistry were above grade level intended and had sizeable internal variation.

Physics Textbooks. Mallinson, Sturm and Mallinson (1952b) reported sizeable range in readability for physics textbooks from grade 7 to college level. Marshall (1962) found no significant relationship between readability of physics textbooks and comprehension of physics materials. Beldon and Lee (1962) reported readabilities of 9.8 to 12.1 for physics textbooks and concluded that these textbooks could be successfully read by most physics students.

College and University Science Textbooks. Majors and Collette (1961) reported that the readabilities of college biology textbooks were written at reading levels at least two years above the average reading abilities of college freshmen. Hogstrom (1971) found that 50% of the college textbooks were too difficult for the intended student. McClellan and McClellan (1976) found only one of 13 textbooks investigated could be considered functional instruction material for the students using the textbooks. Walker (1980) reported that "no significant difference between the grade-level readability of the 1960 and 1978 textbooks.... Likewise, the subjective evaluation of the ... human interest level of the two sets of biology textbooks" had not changed drastically (p. 32). Most science textbooks were considered dull.

Mathematics Textbooks. Esralson (1976) stated that no study related to the reading of science textbooks can ignore the impact of mathematics language" (p. 18). The degree of common terms, symbols, syntax, logical structures and goals between science reading and mathematics reading is undeniable. Curtis (1944) reported 159, 90, 81 and 103 difficult mathematics terms in selected physics, chemistry, biology and general science textbooks. Eskiwani (1973) reported that CHEM study materials required the reader to do 18 different mathematical processes.

Heddens and Smith (1964) and Smith and Heddens (1964) reported that elementary school mathematics textbooks had reading levels that were too high for the intended readers and had considerable internal variation. Covington (1966), Shaw (1967) and Wiegland (1967) supported these results. Nolan (1984) stated

> In general, math texts are written in a terse, unimaginative style, offer few verbal context

clues to help in decoding meaning, and lack redundancy which one finds in most writing.... Math also tends to be highly compact and requires very slow, deliberate reading in order to comprehend the concepts (p. 28).

<u>Summary</u>

Readability research on science materials have generally indicated that:

1. Readability formulas and procedures mean significantly different things.
2. Textbooks are written with reading required at or above the reading ability of the intended reader.
3. The gap beween reading level and reading ability increases with grade level.
4. Extreme internal variation is present in science chapters, science textbooks and science programs.
5. Science textbooks and programs do not have logical reading development from starting chapters to ending chapters or early grades to later grades.
6. Common vocabulary is likely as big an influence as scientific terminology.
7. Future science reading research needs to consider more than the variables traditionally considered in readability formulas, i.e., sentence length, number of syllables, polysyllabic words, and common words.
8. Science textbooks need to be matched to the intended reader.

9. Potential problems might lie in content focus, reference frames, presentation, literary style, linguistic structure, use, type and position of study questions, and use of illustrations.

<u>Science and Early Reading (K-3)</u>

Comparison of the science processes, cognitive abilities and instructional environment in the student-centered science curricula and the reading readiness skills and early reading skills stimulated several research studies. Newport (1969) expressed an interest in determining whether reading readiness skills can be acquired through a less direct approach, namely whether certain science activities might provide an opportunity and climate for the development of reading readiness skills. The observed similarities between the "new" elementary school science curricula and several experienced kindergarten teachers' informal readiness activities leads one to believe the science processes and reading readiness skills are not mutually exclusive. Therefore, science instruction might provide an effective reading readiness program, if not for all pupils, perhaps for pupils of a particular sex. Likewise, Furth (1970) encouraged the development of thinking skills and logical abilities as prerequisites to reading instruction.

<u>Cognitive Development and Reading</u>. Raven and Salzer (1971) applied Piaget's theory to reading. They implied that preoperational reading is little more than attaching labels to specific mental images of objects and operations with little or no generalizability. Raven and Salzer reported that it is

unlikely the preoperational child will have the level of sophistication in classification necessary to "successfully engage in rule learning and application." Almy (1967) and Almy, Chittenden and Miller (1966) suggested conservation and reversibility could be considered prerequisites to formal reading instruction. Raven and Salzer suggested that Piaget's theory implied a nursery school curriculum should stress the interaction of the child and his material environment. The kindergarten should involve the child in a similar experience-oriented curriculum in which reading and books are part of the environment but are not formally taught. The learning situation should be based on the natural social settings of children working, playing, sharing, and learning with others. Worth (1965) pointed out the value of such activities in preschoolers' learning. Waller (1977) summarized much of the correlative research between conservation, classification, seriation and early reading. Stevenson, Parker, Wilkinson, Hegion and Fish (1976), Arlin (1981), and Collis, Ollila and Yore (in press) have confirmed many of these findings. Generally the apparent compelling relationship between individual conservation abilities, logical groupings and infralogical groupings and accepted measure of prereading skills and early reading achievement are small, non-significant and account for little of the variability in reading performance.

Gallagher (1979) encouraged further investigation of the potential relationship between cognitive development and reading, stressing the biological aspects rather than the logical aspects of Piaget's models. Gallagher believes researchers are misguided when they focus their attention on individual logical skills rather than the self-regulation mechanisms of equilibration involving schemata, assimilation, dissonance, and accommodation. Yore and Ollila (1985) found that a global measure of cognitive development helped explain the significant difference in the recognition of concrete words (nouns) and abstract words (non-nouns). Ferreiro and Teberosky (1982) suggested that a Piagetian framework applied to reading means

> that stimuli do not act directly but are transformed by individual's assimilation systems (or assimilation schemes). In this act of transformation, the individual gives an interpretation to the stimulus (to the object, in general terms), and only by virtue of this interpretation does the behavior of the individual become comprehensible.... A particular stimulus (or object) is not the same unless the available assimilation schemes are also the same. This means putting the learner at the center of the learning process, rather than giving the central place to what supposedly directs this learning (the method or the person who carries it out).... Many teachers find themselves trapped in contradictory pedagogical practice when it comes to the two areas that determine the scholastic destiny of the first grade child (elementary math and

> reading/writing).... This contradiction is unacceptable, not only for reasons of pedagogical consistency but also because it is based on two conflicting conceptions of children themselves--creative, active, and intelligent during math time and passive, receptive, and ignorant during reading (pp. 13-14).

Ferreiro and Teberosky believe that children actively construct knowledge about reading and writing similar to their construction of knowledge about mathematics and sciences leading to a constructive reading process. They further suggest that children appropriate the knowledge by means of cognitive conflict where disequilibrium caused by unassimilable objects (physical events, symbolic ideas, words or tasks) force the learners to reorganize their schema or schemata to accommodate the dissonance. Pre-operational children appear to construct a developmental series of unique conceptions about print, such as the name hypothesis, the minimum-quantity hypothesis, the variety of characters hypothesis, picture-print differences, telling-reading operations, and the syllabic hypothesis, that are not transmitted by adults to children. Three precautions guided their research: "reading is not deciphering; writing is not copying a model, and progress in literacy does not come about through advances in deciphering and copying" (p. 272).

Science Instruction and Reading. The effect that science instruction has on reading has been another concern of science educators. Several studies explored the effects of commercially available science programs (SAPA and SCIS) and teacher-developed programs on early reading.

Science: A Process Approach (SAPA). Ayers' (1969) study investigated the effectiveness of A Level, Science: A Process Approach with preschool children. Achievement measured by Ayers' Science Process Test indicated significant gains for three-, four- and five-year-old groups. Ayers' study indicated a significant positive correlation between achievement on the Ayers' Science Process Test and school readiness, as measured by the Metropolitan Readiness Test (MRT). Ayers and Mason (1969) investigated the effect of SAPA on reading readiness of kindergarten children. This study contrasted the effect of SAPA and the regular kindergarten program on reading readiness as measured by the MRT. The analysis of mean gain scored indicated that the science treatment group made significant gains on five subtests (listening, matching, alphabet, numbers, and copying) and the total MRT. Comparisons of mean gain scores between treatment groups indicated significant differences on four subtests (word meaning, listening, numbers, and copying) and the total MRT. Only the word meaning subtest favored the control group with the others favoring the SAPA group. The authors suggested that science activities contained in SAPA appeared to promote reading readiness as measured by the MRT. Ayers and Ayers (1973) found that SAPA was effective in increasing logical thinking of kindergarteners as measured by six Piagetian conservation tasks (number, liquid amount, solid amount, length, weight, and area). Achievement on these conservation tasks correlated significantly with the scores on the MRT.

Ritz and Raven (1970) investigated the effects of a structured process science program and a visual perception program on kindergarten children. Their study contrasted the effects of SAPA with and against the effects of Frostig's Program for the Development of Visual Perception on reading readiness, visual perception, and science process achievement. This was accomplished using a two-phase, blocked instruction, repeated measures design. During the first phase of instruction, two of the three treatment groups received instruction in SAPA and the third received their regular kindergarten program. In the second instructional phase, one of the SAPA groups returned to their regular kindergarten program. Data collected at the end of the first instructional phase favored the SAPA groups on all measures. A significant difference was found on science-process achievement. At the end of the second instructional phase, data indicated significant differences on visual perception measures favoring the treatment groups receiving Frostig's visual perception training. No significant differences were found in reading readiness and science process achievement at the end of the second instructional phase. Ritz and Raven suggested that this study supported the contention that science instruction should be included in kindergartens. They stated that the inclusion of science could be accomplished "without detracting from other important educational outcomes".

Quorn and Yore (1978) found similar significant reading readiness gains (MRT and Clymer-Barrett Pre-reading Battery) in kindergarten children whose training included SAPA and *First Talking Alphabet*. No significant treatment differences, sex differences, or sex-program interaction were found. The second part of the study indicated no significant difference between four programs: (1) informal, (2) *Science: A Process Approach*, (3) *First Talking Alphabet*, (4) control. The results indicated that a more structured approach appeared to produce greater gains.

Kolebas (1971) explored the longitudinal influence SAPA Levels A, B and C have on the science processes and reading achievement of grade 3 students. She found that students exposed to the SAPA program for three years performed significantly better on measures of science process and reading than did the grade 3 control group not exposed to SAPA.

Science Curriculum Improvement Study (SCIS). Renner, Stafford, Coffia, Kellogg and Weber (1973) investigated the question of whether or not the *Material Objects* unit of SCIS is an effective reading readiness program for grade 1 students. The experimental group experienced the *Material Objects* unit and no reading program. The control group experienced a commercial reading readiness program. The MRT was used as a pretest and six weeks later as a posttest. The experimental group out-gained the control group in total score and in the subtest areas: word meaning, listening, matching, alphabet, and numbers. The control group excelled only on the copying subtest. The researchers concluded the superior performance of the experimental group in the listed subtest areas was a result of their having had concrete experiences in these areas to the limit of their interest and ability. Earlier Kellogg (1971) found similar results for the SCIS *Material Objects*.

Morgan, Rachelson and Lloyd (1977) explored the effects of SCIS on grade 1 reading. They found that science group achieved significantly higher reading scores on a school district standardized test than did the non-science group.

Esler and Midgett (1978) reported significant difference between two grade 3 classes on reading comprehension, spelling and language expression. The class utilizing SCIS *Organisms* integrated into the language program demonstrated high reading performance than the class instructed by basal reading and science textbooks by conventional methods. Renner and Coulter (1976) believed that inquiry science programs, like SCIS, provide concrete experiences and an intellectual environment that support reading acquisition and self-actualization.

Other Programs. Darnell and Bourne (1970) explored the effects of training on two-dimensional classification tasks. They measured kindergarten and second grade children's ability to classify concrete objects by width and height. The results indicated significant instruction and age effects. The age effect favored the older children. Non-significant differences were found between the sexes and levels of verbal ability. A highly significant correlation between achievement on the classification tasks and the MRT scores was found for the kindergarten group. The results also produced a significant treatment-by-verbal ability interaction, which seemed to indicate that the more verbal children benefited the most from indirect instruction. Wellman

(1978) reported several other studies that found significant relationships between early reading and science for a wide range of settings and abilities.

Summary

Although the theoretical logical similarities between reading and science processes, reading and concrete experiences, and reading and popular psychological constructs appear compelling, the present research results from read/science explorations are not overwhelming. Future research must build on these results to focus on unanswered questions for unique vantage points as the interactive model of reading, text structure, schemata and conceptual mapping. Generally without reservations these results suggest that science instruction should be part of early schooling, that they likely enhance reading instruction and do not detract from early reading achievement. Weidler (1982) stated

> After reviewing the research in the area of science and reading, it would appear that ... further research [is needed]. Elementary school programs in relation to reading and science need study (p. 56).

READING COMPREHENSION AND SCIENCE ACHIEVEMENT

Comprehension of ideas implied in written text requires an intellectual marriage of writer and reader. The writer must anticipate his readers' prior knowledge, experience and reading schema, and provide a logical set of print stimuli that will allow the reader to construct the meaning intended by the writer.

Anderson and Pearson (1984) provide several illustrations of the influence on comprehension of schema-activation. Two readers with different schemata interpret the same text differently. Anderson and Pearson point out the value of both assimilation of information into existing schema and the modification of schema to accommodate dissonant information. Tierney and Cunningham (1984) synthesized research on prereading activities, interactions during reading and interventions following reading that improve reading comprehension. Research related to preteaching vocabulary, enriching background knowledge and using analogy to build background knowledge prior to reading is mixed and inconclusive regarding the effects of these practices on reading comprehension. Research in activating background knowledge and attention focusing related to reading comprehension appears to support the use of advance organizers and providing students with objectives while the use of pretest and prequestions, student-centered reading activities and pictures, prefactory statements and title require further consideration. Inducing imagery, self-questioning, oral reading, lesson frameworks and study guides were considered as interaction during reading, but research findings were sparse and inconclusive regarding their effects. The effects of teacher interventions following reading, such as postquestions, feedback and group discussions, are inadequately investigated.

Adjunct Aids.

The effects of adjunct questions on reading comprehension and science achievement has been considered by Holliday (1981 & 1983b), Holliday, Whittaker and Loose (1984), and Leonard and

Lowery (1984). Holliday (1981) found that students provided with a comprehensive set of study questions or with no study questions significantly outperformed students with a partial set of study questions. Holliday (1983b) found that overtly prompting students with questions was significantly less effective than unprompted students supplied with adjunct questions. Holliday, et al. (1984) found that study questions have differential effect on readers with different verbal aptitude. Results indicated that verbatim study questions interfered with the science comprehension of readers with low-verbal aptitude. Leonard and Lowery (1984) found science achievement related to reading without questions was superior to science achievement for reading with various types of questions and science achievement with no reading on posttest directly after reading, two weeks after reading and nine weeks after reading. Generally, the type, number and position of adjunct questions in science text to promote greater comprehension and achievement needs further consideration.

The influence of graphic adjuncts on science text comprehension has been explored by several researchers. Holliday (1973 & 1975) found that flow charts were used frequently in science materials in conjunction with prose to illustrate cyclic and/or interactive processes. These graphic adjuncts appeared to increase science comprehension. Holliday, Brunner and Donais (1977) found differential effects of block-word diagrams for readers of different verbal aptitudes. The diagrams appeared to be of less utility to readers with low-verbal aptitudes. Thomas (1978) found that the inclusion or exclusion of pictures in elementary school science textbooks did not appear to affect the students' comprehension. Koran and Koran (1980) explored the placement of graphic adjuncts on the related science achievement. They found non-significant placement and grade effects and significant placement by aptitude interaction. More able students achieved higher scores with no pictorial adjuncts than did less able students. Winn (1980) reported that text-plus-diagrams helped high ability readers to organize concepts more effectively than text only. He found the reverse for low-ability readers. Winn (1981) suggested that diagrams should "show representations of concepts realistically, and they [should] show the relationships between concepts in a particular content area" (p. 31). Winn (1982) found that orientation of diagrams and verbal aptitude of reader significantly influences students science achievement. Brooks (1983) explored the effects of student-generated headings on related science comprehension. Results revealed that generating headings enhances performance on a number of recall measures compared to either author-provided headings or no headings. Williams and Yore (1984) found no significant differences on Cloze scores of science text with or without graphic adjuncts. Winn and Holliday (1982) outlined a set of criteria that graphic adjuncts should consider in order to increase their effectiveness.

Text Structure

Meyer and Rice (1984) state

> In recent years, researchers in the area of reading have been investigating the effects of

> the structure among the ideas presented in a text on what the reader learns and retains from text.... [Text structure refers] to how ideas in a text are interrelated to convey a message to a reader.... Thus, text structure specifies the logical connections among ideas as well as subordination of some ideas to others (p. 319).

Text structure research is a logical extension of earlier readability formulas, except the interrelationships of ideas is paramount rather than number of syllables, sentence length and vocabulary density. Armbruster and Anderson (1981) identified coherence, unity and audience appropriateness as attributes an ideal text should have. Three systems are commonly used to assess text structure, specifically Kintsch (1974), Frederiksen (1975) and Meyer (1975). The Kintsch system considers the hierarchical surface structure and would be appropriate to analyze expository text in which conceptual relationships were not important. Frederiksen's system can be applied to various expository text and utilizes the concept as the basic element of analysis. The system provides a structural graph illustrating the relationship network between concepts much like a concept map. Meyer's system utilizes the idea unit as the basis of the analysis of conceptual relationships. The analysis yields a hierarchy of content structure that indicates propositional relationships, rhetorical relations and arguments.

Meyer and Rice (1984) state

> In summary, these three prose analysis systems

> differ in their strengths and suitability for different types of passages and research questions. Meyer's and Frederiksen's systems are better suited to examining logical relationships and comprehension of these relationships explicitly or implicitly stated in the text (p. 336).

Armbruster and Anderson (1981) illustrated a modified text analysis system that indicates the hierarchical relationships between ideas or frames. Deese (1981) found that text structure affected the comprehension of grades 7 and 10 and college students on a similar biology topic. The results indicated the readers more recall propositions identified as important by content specialists. Finley (1983) used a cluster analysis of recalled physics content to demonstrate that readers recalled common clusters of propositions and more able students recalled greater numbers of clusters. Generally, readers comprehend greater amounts of knowledge from coherent, logically designed, unified and considerate text.

Text, Treatment and Reader

Corey (1977) found that rewriting scientific journals at grade level readability improved the reading rate and comprehension of grade 9 students. Wright (1982) found rewritten science materials to achieve low readability levels significantly improved comprehension measured by Cloze scores but did not improve science achievement measured by a teacher-made test. Tate and Burkman (1983) found that readability, as measured by Cloze scores, of ISIS materials influenced the effects of specific teaching/learning strategies on science achievement and the efficient use of instructional time. Yore (in progress) found that a teaching/learning strategy designed to utilize concrete experience, supplementary reading, direct content reading skill instruction and specific prereading instruction did not overcome the significant effects of general reading vocabulary and general reading comprehension of the students on their science achievement.

RESEARCH TRENDS AND ISSUES IN SCIENCE-READING

Trends in Research

From 1920-50 the emphasis in content reading was on vocabulary and concept load,the main issue being comprehension. The controversy centered on whether definition of a word is sufficient evidence of comprehension or if deeper understanding of the concept is required. The issue has never really been settled.

From 1950-70 the emphasis was on readability, the elusive search for what makes something difficult or easy to read and comprehend. Analyses focused on vocabulary, structure and relationships in text. These analyses became very technical at times (e.g., Anderson's "Kinetic Structure" [1966]).

Though not researched in the context of reading per se, extensive research into epistemological issues--how we know what we know--has been conducted in science education during the past two decades. The problem solving research of the cognitive psychologists has become the focus of research for understanding in science and mathematics learning suggesting yet another level of comprehension--being able to act with knowledge.

Vacca and Vacca (1983), recognizing the seemingly endless complications and issued connected with the search for a single criterion as an explanation of comprehension suggest it might be more productive to think in terms of

> ... multiple levels of knowledge. A very high level of knowledge might be tapped by requiring subjects to demonstrate understanding the concept, perhaps a lower level by requiring selection of production of a definition, and a still lower level by a procedure ... that asks the subject simply to report whether he/she knows the word (p. 89).

It appears there is a trend towards investigation of how meaning is formed in reading that suggests that meaning does not lie outside the reader in the text but is internally constructed by generative mechanisms of intelligence. This attention on what appears to be an essential feature of meaning in reading has led many to emphasize understanding in reading. In fact, Goodman (1975) suggests that if reading is the extraction of meaning, then "reading comprehension" is a redundant phrase, because without comprehension, no reading has occurred. Verbal and mathematical symbolic material appears to be the cues to meaning systems within the reader. One of the trends in reading and science instruction seems to seek deeper understanding of these generative functions which create meaning within students. As research progresses in science education, it seems to become more clear that operational mechanisms underlie linguistic activity in understanding science concepts and these mechanisms are themselves independent of their verbal or symbolic expression.

This trend, which seeks understanding of internal generative mechanisms of meaning, might be termed structuralism because of the emphasis on cognitive patterning or relationships that underlie meaning. Rather than study environmental and other external factors involved in the development of the reading process (drill, effects of controlling vocabulary, phonics instruction, whole word, other teaching techniques), many researchers are probing phonological code (Kleiman, 1975), syntactic structure (Levin & Kaplan, 1970), clausal structure (Forster, 1970), and story structure (Thorndyke, 1977). All these methods suggest that readers must possess complex patterns that allow them to read meaning into textual material.

Another trend of this movement towards structuralism rests in the notion that reading is not a collection of skills but forms a more or less unified system by which specific texts trigger these structural patterns to form a specific instance of a coherent meaning experience. This systems notion seems indicated by the resistance of reading to component analysis. Just as the physical concepts, including conversation concepts, are actually whole systems in which parts are not analyzable separately, so also reading seems to rest on notions of holism. Thorndyke (1973) and Rosenshine (1980) both showed the collapse of distinct comprehension abilities in the face of factor analysis. One verbal factor called comprehension remains. Any discrete factors have so much interaction with other factors they remain indistinguishable from the system as a whole.

Issues for Future Research

The significance of reading appears to be in the grasp of meaning. How to understand even discrete concepts is extremely complicated. Beyond the initial start-up skills, reading instruction seems bound to move more and more towards analysis of meaning and understanding.

The fundamental problem to be overcome by many reading and science education researchers is where to search for the sources and causes of meaning. Do they lie in the language as is suggested in the emphasis on verbal methods of teaching or in the emphasis by researchers on the external influences on the student? Or does meaning rest fundamentally on general laws of the coordination of action systems gradually internalized as intelligence and manifested in structural patterns? There are fundamental contradictions in asserting meaning comes solely from without the learner and it appears the social sciences are gradually moving towards capturing the internal subjectivity of human knowing by the very emphasis on structural patterns and relationships in research.

Walker (1981) stressed that the textbook is much maligned and little studied. Walker believes naturalistic field studies are required to more fully explore text-related learning and teaching. Stewart and Atkin (1982) propose the information processing paradigm as an alternative model to guide science education research related to learning and problem solving. Stewart and

Atkin neglected to specifically mention science-reading research as a potential area to apply information processing strategies. Ulerich (1983) suggests that there was a significant need to explore the role the text has in the teaching and learning of science. She points out that special consideration is needed to define and describe the content differences in the instructional treatments as they relate to outcomes in the information processing model.

Readability formulas present special problems in the area of science. Formulas based on word difficulty and sentence structure fail to account for both reader and content characteristics. Texts written to conform to a reading formula may be made more difficult to comprehend in the process.

The activity dimension of science provides a fertile area for re-establishing what it means to comprehend science text material. New measures of readability (comprehensibility) no doubt will reflect an interactive, construction model of knowing. Vygotsky's research on "proleptic" learning, which studies the reader's ability to anticipate meaning from text patterns and structure, and the work on "scaffolding" support an interactive model of reading comr ehension and suggest a new round of reading research that treats the reader as more than a mechanic and the material to be learned as more than a set of symbols.

REFERENCES

Allington, R.L., & Strange, M. (1980) Learning Through Reading in the Content Areas. Toronto: D.C. Heath & Co.

Almy, M. (1967) Young children's thinking and the teaching of reading. In J.L. Frost (Ed.) Issues and Innovations in the Teaching of Reading. New York: Scott, Foresman.

Almy, M., Chittenden, E., & Miller, P. (1966) Young Children's Thinking Studies of Some Aspects of Piaget Theory. New York: Teacher College Press.

Anderson. O.R. (1966) A refined definition of structure in teaching. Journal of Research in Science Teaching, 4, 289-291.

Anderson, R.C. (1978) Schema directed processes in language comprehension. In A.M. Lesgold, J.W. Pelligrino, S.D. Fokkema & R. Glaser (Eds.) Cognitive Psychology and Instruction. New York: Plenum.

Anderson, R.C., & Pearson, P.D. (1984) A schema-theoretic view of basic processes in reading comprehension. In P.D. Pearson, R. Barr, M.L. Kamil & P. Mosenthal (Eds.) Handbook of Reading Research. New York: Longman, 255-291.

Anderson, R.C., Spiro, R.J., & Anderson, M.C. (1978) Schemata as scaffolding for the representation of information on connected discourse. American Educational Research Journal, 15, 4[illegible]3-440.

Arlin, P.K. (1981) Piagetian tasks as predictors of reading and math readiness in grades K-1. Journal of Educational Psychology, 73, 712-721.

Armbruster, B.B., & Anderson, T.H. (1981) Analysis of science textbooks: implications for authors. In J. T. Robinson (Ed.) Research in Science Education: New Questions; New Directions. Columbus, OH: ERIC, Science, Mathematics and Environmental Education, 21-52.

Ausubel, D.P., Novak, J.D., & Hanesian, H. (1978) Educational Psychology: A Cognitive View. New York: Holt, Rinehart & Winston.

Ayers, J.B. (1969) Evaluation of the use of Science: A Process Approach upon change in Metropolitan Readiness Test scores among kindergarten children. The Reading Teacher, 5, 435-439.

Ayers, J.B., & Mason, G.E. (1969) Differential effects of Science: A Process Approach upon change in Metropolitan Readiness Test scores among kindergarten children. The Reading Teacher, 22, 435-439.

Ayers, M.N., & Ayers, J.B. (1973) Study of Kindergarten Pupils' Use of Logic in Problem Solving through SAPA. Presentation to American Educational Research Association, New Orleans, Louisiana, February.

Baker, L., & Brown, A.L. (1984) Metacognitive skills and reading. In P.D. Pearson, R. Barr, M.L. Kamil & P. Mosenthal (Eds.) Handbook of Reading Research. New York: Longman, 353-394.

Beldon, B.R., & Lee, W.D. (1961) Readability of biology textbooks and reading ability of biology students. School Science and Mathematics, 61, 689-693.

Brooks, L.W. (1983) Generation of descriptive test headings. Contemporary Educational Psychology, 8, 103-108.

Brown, A.L. (1982) Learning how to learn from reading. In J.A. Langer & M.T. Smith-Burke (Eds.) Reader Meets Author/Bridging the Gap. Newark, Delaware: International Reading Association, 26-54.

Bruce, B.C., & Newman, D. (1978) Interacting plans. Cognitive Science, 2, 195-233.

Burkey, J.E. (1954) The readability level of recently published elementary science textbooks. Unpublished Ph.D. dissertation, University of Pittsburgh.

Cassidy, J. (1977) Reading (math, science, social studies, english, survival) C.A.R.E. (Content Area Reading Enrichment). Teacher, 94, 70-72.

Chall, J.S. (1983) Stages of Reading Development. New York: McGraw-Hill.

Chomsky, N. (1957) Syntactic Structures. The Hague: Mouton.

Collis, B., Ollila, L.O., & Yore, L.D. (in press) Correlation of Canadian Readiness Test, measures of cognitive and grade one achievement. Alberta Journal of Education.

Connors, J. (1977) Readability. Unpublished paper, University of Iowa.

Corey, N.R. (1977) The use of rewritten science materials in ninth grade biology. Journal of Research in Science Teaching, 14, 97-103.

Covington, R. (1966) An analysis of readability of third and fourth grade modern mathematics textbooks using the Cloze procedure. Unpublished Ed.D. dissertation, University of California, Los Angeles.

Curtis. F.D. (1944) The mathematics vocabulary in textbooks of science. Journal of Educational Research, 38, 124-131.

Dale, E., & Chall, J.S. (1948) A formula for predicting readability. Education Research Bulletin, 27, 11-20, 28.

Darnell, C., & Bourne, L. (1970) Effects of age, verbal ability, and pretraining with component concepts of performance of children in bidimensional classification task. Journal of Educational Psychology, 61, 66-71.

Daugs, D.R., & Daugs, F. (1974) Readability of high school biology materials. Science Educatinn, 58, 471-482.

Deese, J. (1981) Text structure strategies and comprehension in learning from scientific textbooks. In J.T. Robinson (Ed.) Research in Science Education: New Questions: New Directions. Columbus, OH: ERIC Science, Mathematics and Environmental Education, 53-68.

Denslow, O.D. (1961) Vocabulary and sentence study of eight first-grade science books. Elementary English, 38, 487-490.

Doran, R.L., & Sheard, D.M. (1974) Analyzing science textbooks. School Science and Mathematics, 74, 31-39.

Eisenberg, A. (1977) Lexical, syntactic and semantic characteristics of the language of science. ERIC: ED 149 289.

Eshiwani, G.S. (1973) The Chem study and Nuffield chemistry: a comparison. School Science and Mathematics, 73, 3-8.

Esler, W., & Midgett, B. (1978) Using laboratory experiences to teach reading. Science and Children, February 15, 33-34.

Esra..son, L. (1976) A comparative readability study of selected high school chemistry textbooks. Unpublished Master of Education project, University of Victoria.

Esralson, L. (1978) Readability of science textbooks. Paper presented at Transmountain Regional Meeting of Internatinal Reading Association, Vancouver, B.C., March.

Ferreiro, E., & Teberosky, A. (1982) Literacy Before Schooling. Translated by K. Goodman-Castro. Exeter: Heinemann.

Finley, F.N. (1983) Students' recall from science text. Journal of Research in Science Teaching, 20, 247-259.

Flesch, R. (1948) A new readability yardstick. Journal of Applied Psychology, 32, 221-233.

Forster, K.I. (1970) Visual perception of rapidly presented word sequences of varying complexity. Perception and Psychophysics, 8, 215-221.

Fredericks, E.C. (1968) A study of the effects of readiness activities on concept learning. Unpublished doctoral dissertation, Syracuse University.

Frederiksen, C.H. (1975) Acquisition of semantic information from discourse: effects of repeated exposures. Journal of Verbal Learning and Verbal Behavior, 14, 158-169.

Fry, E. (1968) A readability formula that saves time. Journal of Reading, 11, 513-516, 575-578.

Fry, E. (1977) Fry's readability graph: clarifications, validity and extension to level 17. Journal of Reading, 21, 242-252.

Furth, H.G. (1970) Piaget for Teachers. Englewood Cliffs, NJ: Prentice-Hall.

Gallagher, J.M. (1979) Problems in applying Piaget to reading, or letting the bird out of the cage. Boston University Journal of Education, 161, 72-86.

Gardner, P.L. (1980) The identification of specific difficulties with logical connectives in science among secondary school students. Journal of Research in Science Teaching, 17, 223-229.

Gardner, P.L., Schafe, L., Myint-Thein, U., & Watterson, R. (1976) Logical connectives in science: some preliminary findings. Research in Science Education: Proceedings of the Seventh Annual Conference of the Australian Science Education Research Association, 7, 97-108.

Gilbert, C.D. (1973) An examination of readability levels for selected basic science texts. School Science and Mathematics, 73, 747-758.

Goodman, K.S. (1976) Reading: a psycholinguistic guessing game. In H. Newman (Ed.) Reading: Process and Product. Forest Hills, NY: Prestige Educational.

Goodman, Y. (1975) Reading comprehension - the redundant phrase. Michigan Reading Journal, 9, 27-36.

Gough, P.B. (1972) One second of reading. In J.F. Kavanagh & I.G. Mattingly (Eds.) Language by Ear and Eye. Cambridge: MIT Press.

Heddens, J.W., & Smith, K.J. (1964) The readability of elementary mathematics books. The Arithmetic Teacher, 11, 466-468.

Hogstrom, J.A. (1971) A comparison of the reading abilities of a junior college population and the readability of the textbooks. ERIC ED 050 902.

Holler, R.L. (1969) The readability of selected tenth-grade biology text materials. Unpublished E.D. dissertation, University of Maryland.

Holliday, W.G. (1973) Critical analysis of pictorial research related to science education. Science Education, 57, 201-214.

Holliday, W.G. (1975) What's in a picture? The Science Teacher, 42, 21-22.

Holliday, W.G. (1981) Selective attentional effects of textbook study questions in student learning in science. Journal of Research in Science Teaching, 18, 283-289.

Holliday, W.G. (1983a) Using recent research methods based in cognitive psychology to evaluate science textbooks. Paper presented at National Association for Research in Science Teaching Annual Meeting, Dallas, TX, April 5-8.

Holliday, W.G. (1983b) Overprompting science students using adjunct study questions. Journal of Research in Science Teaching, 20, 195-201.

Holliday, W.G., Brunner, L.L., & Donais, E.L. (1977) Differential cognitive and affective responses to flow diagrams in science. Journal of Research in Science Teaching, 14, 129-138.

Holliday, W.G., Whittaker, H.G., & Loose, K.D. (1984) Differential effects of verbal aptitude and study questions on comprehension of science concepts. Journal of Research in Science Teaching, 21, 143-150.

Johnson, N.S., & Mandler, J.M. (1980) A tale of two structures: underlying and surface forms in stories. Poetics, 9, 51-86.

Kellogg, D. (1971) An investigation of the effect of the science curriculum study's first year unit, material objects, on gain in reading readiness. Doctoral dissertation, University of Oklahoma, University Microfilms 71-27, 623.

Kennedy, K. (1974) Reading level determination for selected texts. The Science Teacher, 41, 26-27.

Kintsch, W. (1974) The representation of meaning in memory. New York: Lawrence Erlbaum.

Kintsch, W., & van Dijk, T.A. (1978) Toward a model of text comprehension and production. Psychology Review, 85, 363-394.

Kitzmiller, A.B. (1931) Certain vocabulary problems in high school chemistry. Science Education, 15, 33-43.

Kleiman, G.M. (1975) Speech recoding and reading. Journal of Verbal Learning and Verbal Behavior, 9, 27-36.

Kline, L.E. (1966) Textbook readability and other factors which could influence the success of the eighth-grade earth science course in the Texas public schools. Unpublished Ph.D. dissertation, East Texas State University.

Knight, L.N., & Hargis, C.H. (1977) Math language ability: its relationship to reading math. Language Arts, 54, 423-428.

Kolebas, P. (1971) The effects on the intelligence, reading, mathematics, and interest in science levels of third grade students who have participated in Science: A Process Approach since first entering school. Doctoral dissertation. University of Virginia, Charlottesville.

Koran, M.L., & Koran, J.J. (1980) Interaction of learner characteristics with pictorial adjuncts in learning from science text. Journal of Research in Science Teaching, 17, 477-483.

LaBerge, D., & Samuels, S.J. (1977) Toward a theory of automatic information processing in reading. Cognitive Psychology, 6, 293-323.

Lee, W.D., & Hislop, M.E. (1968) Problems involved in placement of students in a biology class. School Science and Mathematics, 68, 473-476.

Leonard, W.H., & Lowery, L.F. (1984) The effects of question type in textual reading upon retention of biology concepts. Journal of Research in Science Teaching, 21, 377-384.

Levin, H., & Kaplan, E.L. (1970) Grammatical structure and reading. In H. Levin & J. Williams (Eds.) Basic Studies on Reading. New York: Basic Books.

Lira, J.R. Active comprehension in progress. ERIC: ED 195 927.

Lorge, I. (1944) Predicting readability. Teacher College Record, 45, 404-419.

Major, A.G., & Collette, A.T. (1961) The readability of college general biology textbooks. Science Education, 45, 216-224.

Mallinson, G.G., Sturm, H.E., & Patton, R.E. (1950) The reading difficulty of textbooks in elementary education. The Elementary School Journal, 50, 460-463.

Mallinson, G.G., Sturm, H.E., & Mallinson, L.M. (1950) The reading difficulty of textbooks for high-school biology. The American Biology Teacher, 12, 151-156.

Mallinson, G.G., Sturm, H.E., & Mallinson, L.M. (1952a) The reading difficulty of textbooks for high-school chemistry. Journal of Chemical Education, 29, 629-631.

Mallinson, G.G., Sturm, H.E., & Mallinson, L.M. (1952b) The reading difficulty of textbooks for high-school physics. Science Education, 36, 19-23.

Mallinson, G.G., Sturm, H.E., & Mallinson, L.M. (1954) The reading difficulty of textbooks for general physical science and earth science. School Science and Mathematics, 54, 612-616.

Mandler, J.M., & Johnson, N.S. (1977) Remembrance of things parsed: story structure and recall. Cognitive Psychology, 9, 111-151.

Marshall, J.S. (1962) Comprehension and alleged readability of high school physics textbooks. Science Education, 45, 335-346.

Marshall, N., & Glock, M. (1978-79) Comprehension of connected discourse: a study into the relationship between the structure of text and information recalled. Reading Research Quarterly, 14, 10-56.

Martin, M. (1962) Refinement of a readability formula. In E.P. Bliesmer & R.C. Staiger (Eds.) Problems, Programs and Projects in College-Adult Reading. Eleventh Yearbook of Natural Reading Conference, 131-138.

McClellan, D.A., & McClellan, L. (1976) A comparison of the readability level of text materials with the reading level of community college students. ERIC ED 123 578.

McLaughlin, G.H. (1969) SMOG grading--a new readability formula. Journal of Reading, 12, 639-646.

Meyer, B.J. (1975) The Organization of Prose and Its Effects on Memory. Amsterdam: North-Holland Pub. Co.

Meyer, B.J., & Rice, G.E. (1984) The structure of text. In P.D. Pearson, R. Barr, M.L. Kamil, & P. Mosenthal (Eds.) Handbook of Reading Research. New York: Longman, 319-351.

Morgan, A., Rachelson, S., & Lloyd, B. (1977) Sciencing activities as contributors to the development of reading skills in first grade students. Science Education, 61, 135-144.

Newport, J.F. (1965) The readability of science textbooks for elementary school. The Elementary School Journal, 66, 40-43.

Newport, J.F. (1969) Can experiences in science promote reading readiness? The Elementary School Journal, April, 375-380.

Nolan, J.F. (1984) Reading in the content area of mathematics. In Reading in the Content Areas: Research for Teachers. Newark, Delaware: International Reading Association, 28-41.

Opwood, G.W., & Souque, J.P. (1984) Science Education in Canadian Schools, Vol. I. Ottawa: Science Council of Canada.

O'Toole, R.J., & Bedford, J.P. (1969) Science vocabulary and readability level. Journal of Research in Science Teaching, 6, 161-162.

Ottley, L. (1965) Readability of science textbooks for grades four, five and six. School Science and Mathematics, 65, 363-366.

Pearson, P.D., & Spiro, R. (1982) The new buzz word in reading is schema. Instructor, May, 46-48.

Piercey, D. (1976) Reading Activities in Content Areas. Boston: Allyn & Bacon.

Pikulski, J.J., & Jones, M.B. (1977) Writing directions children can read. The Reading Teacher, 30, 598-602.

Powell, M.M. (1966) An analysis of reading levels and content of the Alabama state-adopted high school chemistry text for the year 1964-65. Unpublished Ph.D. dissertation, University of Alabama.

Powers, S.R. (1924) The vocabularies of high school science textbooks. Teachers College Record, 26, 368-382.

Powers, S.R. (1926) A vocabulary of scientific terms for high school students. Teachers College Record, 28, 220-245.

Pronger, E.L., Johnson, T.D., & Yore, L.D. (1983) The effects of repeated presentations of a story on recall and comprehension of grade one students. Paper presented at Transmountain Conference of International Reading Association, March 7-9.

Quorn, K.C., & Yore, L.D. (1978) Comparison studies of reading readiness skills acquisition by different methods: formal reading readiness program, informal reading readiness program, and a kindergarten science program. Science Education, 62, 459-465.

Raven, R., & Salzer, R. (1971) Piaget and reading instruction. The Reading Teacher, 5, 216-223.

Renner, J.W., & Coulter, V.J. (1976) Science achievement is above expectations in Norman, Oklahoma. Science and Children, 13, 26-27.

Renner, J.W., Stafford, D.G., Coffia, W.J., Kellogg, D.H., & Weber, M.C. (1973) An evaluation of the Science Curriculum Improvement Study. School Science and Mathematics, 73, 291-318.

Ricker, K.S. (1978) But can they read it? A look at readability formulas. Science Teacher, 45(3), 22-24.

Ritz, W.C., & Raven, R.J. (1970) Some effects of structured science and visual perception instruction among kindergarten children. Journal of Research in Science Teaching, 7, 179-186.

Robinson, J.T. (1964) Understanding of BSCS biology students as determined by instructional tests. Cooperative Research Project No. 1967. Claremount Graduate School, Claremount, CA.
Lee, W.D., & Hislop, M.E. (1968) Problems involved in placement of students in a biology class. School Science and Mathematics, 68, 473-476.

Rosenshine, B.V. (1980) Skill hierarchies in reading comprehension. In R.J. Spiro, B.C. Bruce & W.F. Brewer (Eds.) Theoretical Issues in Reading Comprehension: Perspectives from Cognitive Psychology, Linguistics, Artificial Intelligence and Education. Hillsdale, NJ: Erlbaum.

Rumelhart, D.E. (1976) Toward an Interactive Model of Reading. San Diego: Center for Human Processing Technical Report No. 56. University of California.

Rumelhart, D.E. (1977) Understanding and summarizing brief stories. In D. LaBerge & S.J. Samuels (Eds.) Basic Processes in Reading: Perception and Comprehension. Hillsdale, NJ: Lawrence Erlbaum, 265-303.

Rystrom, R. (1977) Reflections of meaning. Journal of Reading Behavior, 9, 193-200.

Samuels, S.J., & Kamil, M.L. (1984) Models of the reading process. In P.D. Pearson, R. Barr, M.L. Kamil & P. Mosenthal (Eds.) Handbook of Reading Research. New York: Longman. 185-224.

Schallert, D.L., & Kleiman, G.M. (1979) Some reasons why the teacher is easier to understand than the textbook. ERIC ED 172-189.

Shaw, J.A. (1967) Reading problems in mathematics texts. Unpublished paper. School of Education, San Diego State College, CA.

Shymansky, J.A., & Yore, L.D. (1979) Assessing and using readability of elementary science textbooks. School Science and Mathematics, 79, 670-676.

Smith, H.H. (1980) What they didn't tell you about Jack and Jill: an aspect of reading comprehension. Journal of Reading, 24, 101-108.

Smith, K.J., & Heddens, J.W. (1964) The readability of experimental mathematics materials. The Arithmetic Teacher, 11, 391-394.

Spache, G. (1953) A new readability formula for primary grades. The Elementary School Journal, 53, 410-413.

Spiro, R.J. (1980) Constructive processes in prose comprehension and recall. In R.J. Spiro, B.C. Bruce & W.F. Brewer (Eds.) Theoretical Issues in Reading Comprehension. Hillsdale, NJ: Lawrence Erlbaum, 245-278.

Stein, H.L., & Glenn, C.G. (1979) An analysis of story comprehension in elementary school children. In R.O. Freedle (Ed.) New Directions in Discourse Processing, Vol. 2 of Advances in Discourse Processing. Norwood, NJ: Ablex, 53-120.

Stevenson, H.W., Parker, T., Wilkinson, A., Hegion, A., & Fish, E. (1976) Longitudinal study of individual differences in cognitive development and scholastic achievement. Journal of Educational Psychology, 68, 377-400.

Stewart, J.H., & Atkin, J.A. (1982) Information processing psychology: a promising paradigm for research in science teaching. Journal of Research in Science Teaching, 19, 321-332.

Strange, M. (1980) Instructional implications of a conceptual theory of reading comprehension. The Reading Teacher, 33, 391-397.

Tate, R., & Burkman, E. (1983) Interactive effects of source of direction, allocated time, reading ability, and study orientation on achievement in high school science. Science Education, 67, 523-540.

Taylor, W.L. (1953) Cloze procedure: a new tool for measuring readability. Journalism Quarterly, 30, 415-433.

Thelen, J.N. (1984) Improving Reading in Science. Newark, Delaware: International Reading Association.

Thomas, J.L. (1978) The influence of pictorial illustrations with written text and previous achievement on the reading comprehension of fourth grade science students. Journal of Research in Science Teaching, 15, 401-405.

Thorndyke, P.W. (1977) Cognitive structures in comprehension and memory of narrative discourse. Cognitive Psychology, 9, 77-110.

Thorndyke, R.L. (1973) Reading as reasoning. Reading Research Quarterly, 9, 135-147.

Tierney, R.J., & Cunningham, J.W. (1984) Research on teaching reading comprehension. In P.D. Pearson, R. Barr, M.L. Kamil & P. Mosenthal (Eds.) Handbook of Reading Research. New York: Longman, 609-655.

Ulerick, S.L. (1983) A critical review of research related to learning from science textbooks. Paper presented at National Association for Research in Science Teaching, Dallas, TX, April 5-8.

Vacca, R.T. (1977) Readiness to read content area assignments. Journal of Reading, 20, 387-392.

Vacca, R.T., & Vacca, J.L. (1983) Re-examining research on reading comprehension in content areas. In B.A. Hutson (Ed.) Advances in Reading Language Research. Greenwich, CT.

Vachon, M.K., & Haney, R. (1983) Analysis of concepts in an eighth grade science textbook. School Science and Mathematics, 83, 236-245.

Walker, D.F. (1981) Learning science from textbook: toward a balanced assessment of textbook in science education In J.T. Robinson (Ed.) Research in Science Education: New Questions: New Directions. Columbus, OH: ERIC Science, Mathematics and Environmental Education, 5-20.

Walker, N. (1980) Readability of college general biology textbooks: revisited. Science Education, 64, 29-34.

Waller, T.G. (1977) Think First, Read Later! Piagetian prerequisites for Reading. Newark, Delaware: International Reading Association.

Weidler, S.D. (1984) Reading in the content area of science. In M.M. Dupuis (Ed.) Reading in the Content Areas: Research for Teachers. Newark, Delaware: International Reading Association, 54-65.

Wellman, R.T. (1978) Science: a basic for language and reading development. In M.B. Rowe (Ed.) What Research Says to the Science Teacher. Washington, DC: National Science Teachers Association, -12.

Wiegand, R.B. (1967) Pittsburgh looks at the readability of mathematics textbooks. Journal of Reading, 11, 201-204.

Williams, R.L., & Horne, J.C. (1978) Criteria for physical science textbooks; they still use textbooks, don't they. School Information and Research Service, State of Washington Department of Education, Olympia, January, 37-42.

Williams, R.L., & Yore, L.D. (1985) Content, format, gender and grade level differences in elementary students' ability to read science materials as measured by the Cloze procedure. Journal of Research in Science Teaching, 22, 81-88.

Winn, W. (1980) The effect of block-word diagrams on the structuring of science concepts as a function of general ability. Journal of Research in Science Teaching, 17, 201-211.

Winn, W. (1981) Effect of attribute highlighting and diagrammatic organization on identification and classification. Journal of Research in Science Teaching, 18, 23-32.

Winn, W. (1982) The role of diagrammatic representation in learning sequences, identification and classification as a function of verbal and spatial ability. Journal of Research in Science Teaching, 19, 79-89.

Winn, W., & Holliday, W.G. (1982) Design principles for diagrams and charts. In D. Jonassen (Ed.) The Technology of Text: Principles for Structuring, Designing and Displaying Text. Englewood Cliffs, NJ: Educational Technology Publications.

Worth, W. (1965) The critical year. The B.C. Teacher, 44, 239-241.

Wright, J.D. (1982) The effect of reduced readability text materials on comprehension and biology achievement. Science Education, 66, 3-13.

Yore, L.D. (1979a) A practical analysis of readability part I: space, time, energy and matter. The B.C. Science Teacher, 20(3), 10-12.

Yore, L.D. (1979b) A practical analysis of readability part II: exploring science. The B.C. Science Teacher, 20(3), 19-21.

Yore, L.D. (1979c) Readability update: Science Seven B. The B.C. Science Teacher, 21(1), 9-10.

Yore, L.D. (1979d) Having difficulty with Examining Your Environment? It may be the readability of the student text! The B.C. Science Teacher, 21(2), 3-8.

Yore, L.D. (in progress) Grade five students' science achievement and ability to read science textbooks as a function of sex and Gates-MacGinitie vocabulary and comprehension scores.

Yore, L.D., & Ollila, L.O. (1985) Cognitive development, sex and abstractness in grade one word recognition. Journal of Educational Research, 78, 242-247.