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ABSTRACT

The purpose of this paper is to update the review of science-related reading research conducted by Yore and Shymansky (1985) and to provide a current research foundation for a science reading research agenda. This review emphasizes the post-1985 literature and selected pre-1985 literature not included in the earlier summary. This summary addresses the interactive-constructive model of reading, the science reader, textbooks in science teaching, comprehension instruction, and future directions. The conclusions drawn from the review indicate that existing school programs do little to help students comprehend science text and that some comprehension strategies for expository text respond positively to explicit instruction. Much of the research reviewed disregarded the unique attributes of science, scientific language, context, and conceptual change. A major shortcoming of current research is the definition and assessment of comprehension. Greater effort is required to measure knowledge constructions, meaningful learning, and implicit comprehension over a period of time. The use of think-alouds, structured interview protocols, concept maps, two-part objective questions, and performance tasks have potential application in science reading research. (Contains over 100 references.) (PR)

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REVIEW OF READING COMPREHENSION INSTRUCTION:
1985 - 1991

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Introduction

The interest in comprehending printed science materials has varied over the last 50 years. The 1950s emphasized reading about natural sciences, the 1960s emphasized hands-on activity-oriented science, the 1970s emphasized a blend of text and activities, the 1980s emphasized computer applications, and the 1990s are emphasizing hyper-media and telecommunications. While the popularity of scientific textual materials has ebbed and flowed, the central issue of how learners process information irrespective of its form or source to construct meaning has received limited attention.

It is likely that the source of information, whether it be primary information (personal experience), secondary information (recorded visual and verbal experiences), or tertiary information (someone else's recollections and interpretations of experience) is less important than the cognitive and metacognitive dimensions involved in making sense of the information, constructing understanding, and

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inventing meaning. Consideration of reading comprehension of science materials may be an appropriate starting point in the exploration of this general issue, not because of the importance of textual materials but rather because of the rich foundation of reading research into narrative text and non-scientific expositive text. Contemporary models of reading are closely aligned with current models of science learning; both areas are grounded in a constructivist paradigm. The constructivist perspectives that are based on the early work of Vico, Kant, Dewey, Piaget, and Vygotsky have received increased attention since cognitive scientists began searching for alternative models of learning. The rediscovery of the importance of prior knowledge, heuristics, meaning-making, and executive control of learning are unifying themes across reading comprehension and science learning.

The purpose of this paper is to update the review of science related reading research conducted by Yore and Shymansky (1985) and to provide a current research foundation for a science reading research agenda (Yore, 1986). This review emphasizes the post-1985 literature and selected pre-1985 literature not included in the earlier summary. This summary addresses the interactive-constructive model of reading, the science reader, textbooks in science teaching, comprehension instruction, and future directions.

Interactive-Constructive Reading Model

A significant paradigm shift has occurred in how learning is viewed. A unifying movement has highlighted the

commonalities in thinking, problem solving, reading comprehension, science learning, and mathematics learning while recognizing the unique nature of these disciplines (Yore & Russow, 1989). As researchers have constructed more and more insightful interpretations of cognition, traditional interpretations have been subsumed, increased predictive power has been provided, and clearer associations between learner attributes, motivation, intention, effort, self-efficacy and achievement have been hypothesized.

Currently, science reading can be conceptualized as an interaction between what is known, concurrent sensory experience, and information accessed from print in a specific context that is directed at constructing meaning. Readers must interactively process information by instantly switching back and forth between selective perceptions of text-based information and concurrent experience on the one hand and by comparing the information and experience with their personal world-view recollections in short-term memory on the other hand (Holliday, 1988; Kintsch & Van Dijk, 1978; Osborne & Wittrock, 1983; Yore & Shymansky, 1991). Readers increase or change their understanding by extracting information from the text-based situation (print, charts, pictures) and concurrent experiences (senses, other people) — called bottom-up processing, by retrieving information from their long-term episodic and semantic memories and deciding what should be considered in a specific context (task, cultural, social, conceptual) — called top-down processing, while monitoring,

strategically planning, and regulating the global meaning-making process. Thus, cognition is an interactive-constructive process; and metacognition is a conscious consideration of this generative process that results in verifying, structuring, and restructuring information into meaningful knowledge networks called schemata. The success of establishing valid factual associations within the conceptual nodes in the network and associated linkages between nodes determines the degree of reading comprehension, the applicability of schemata, and the retrievability of the understanding from long-term memory. Future understanding depends, first, on the variety, richness, and organization of prior experience and, second, on whether or not these experiences have been stored as prior knowledge making them available for retrieval from the reader's schemata.

Samuels (1983) stated that "no longer do we think of reading as a one-way street from writer to reader, with the reader's task being to render literal interpretation of text" (p. 260). Valencia and Pearson (1987) stated that the interactive-constructive view:

> emphasizes the active role of readers as they use print clues to 'construct' a model of the text's meaning. It deemphasizes the notion that progress toward expert reading is the aggregation of component skills. Instead, it suggests that at all levels of sophistication, from kindergarten to research scientist, readers use available resources (e.g., text, prior knowledge, environmental

> clues, and potential helpers) to make sense of text. (p. 727)

Osborne and Wittrock (1983) broadened the horizon when they stated:

> to comprehend what we are taught verbally, or what we read, or what we find out by watching a demonstration or doing an experiment, we must invent a model or explanation for it that organizes the information selected from the experience in a way that makes senses to us, that fits our logic or real world experiences, or both. (p. 493)

Wittrock, Marks, and Doctorow (1975) pointed out that this creative construction process utilizes more than the sum of ideas and clues embedded in the information source or stored in long-term memory.

Flood (1986) stated:

> readers approach texts as blue-prints, as guides that enable them to construct meaning. Texts establish broad limits of possible meanings, but they do not specify a single meaning. Readers (not texts) create meaning through negotiations with authors. This current view makes sense when one realizes that writers are constrained to convey multidimensional thought in unidimensional space. Writers' thoughts and feeling cannot be presented as entities to be grasped serially, unit by unit. Writers' thoughts are complex, interwoven

webs, yet they can only be transmitted unidimensionally (pp. 784-785).

Van Dijk and Kintsch (1983) described these real-time negotiations as a conflict resolution process that progressively solves meaning problems involving text-based interpretations extracted from print, the reader's episodic memory and semantic memory, and the situation's cultural context. Episodic memory involves stored recollections of the conceptual topic; semantic memory involves the reader's world-view of language structures, linguistic rules, science text, and the scientific enterprise; while the cultural context involves practices, standards, beliefs, and expectations that set boundaries for acceptable resolutions.

The interactive-constructive model of reading not only recognizes the inherent difficulties of capturing multidimensional experiences utilizing the writing process, accepts the existence of contextual influences, de-emphasizes the aggregation of individual skills leading to expert reading status, and stresses the importance of prior knowledge, but it also emphasizes the awareness and control of the reading process. Flavell (1979) described this dimension that deals with people thinking about and orchestrating their thinking as metacognition. Brown, Bransford, Ferrara, and Campione (1983) described metacognition as the executive control of cognition involving planning, monitoring, revising, and repairing understanding. Many of these executive strategies are automatic to an expert reader, and only when the demands

of cognition overburden this automaticity does metacognition become a conscious public act composed of two clusters — self-appraisal and self-management.

Jacobs and Paris (1987) suggested that self-appraisal consists of three categories of reading knowledge: (1) declarative knowledge of the specified task, (2) procedural knowledge of the cognitive processes involved, and (3) conditional knowledge of what influences the processes and when the processes should be used. The self-management dimension involves: (1) the strategic planning of the action, (2) the monitoring of progress, and (3) the regulation of the action. Planning involves goal setting, accessing prior knowledge, identifying additional information sources, and selecting appropriate strategies. Monitoring involves self-questioning, reviewing, and testing. Regulation involves effort and alternative strategies.

Science Reader

Viewed from the perspective of the interactive-constructive reading model, the science reader's prior knowledge, strategies, and metacognition are critical. Garner (1987) mentioned some of these prerequisites: accessible relevant conceptual knowledge, text structure schemata for science text, and text proc. ssing strategies (summarization and strategic backtracking). The image of an effective, efficient science reader has been described by a 21-factor model based on research results (Yore & Denning, 1989; Yore & Craig, 1990). Younger and poorer readers have less awareness of the reading

process and their own weaknesses. They therefore are less able to select appropriate strategies and to correct any comprehension problems, while better readers monitor their performance and take corrective actions when comprehension fails.

Prior knowledge of the topic under consideration is more important in science reading than in narrative reading because of the unique nature of science and the conceptual density of scientific textual material. The inability of many students to relate new information and old knowledge results in the text-based message being meaningless.

Existing or prior knowledge in the science topic being presented is not always helpful and even may be a hindrance. Alvermann, Smith, and Readence (1985) reported that often students are in possession of naive concepts for scientific phenomena when they encounter formal science teaching, and so they may experience conflict between the two belief systems. According to Maria and McGinitie (1987), text structures that explicitly contrast and engage readers' misconceptions were more effective than texts that simply stated the correct information. Poor comprehenders frequently listed both the misconception and the correct conception without recognizing any contradiction.

Although Holmes (1983) reported non-significant differences between poor and better readers on explicit comprehension tasks, significant differences were found on implicit comprehension tasks. Good readers who possessed a

high level of prior knowledge about the topic were able to make good use of this understanding in answering questions, but poor readers with high prior knowledge were not. These findings suggest that the major problem for poor readers in answering inferential questions is not simply a lack of prior knowledge but rather difficulty in drawing inferences from material spanning more than one sentence. Poor readers tend to adopt a passive rather than an active reading style, one that involves self-monitoring of comprehension and the use of compensatory strategies when problems are encountered. Prior knowledge assists good readers process text in depth, but does not help poor readers because they are unable to use it as a structure for integrating new information.

In contrast, Recht and Leslie (1988) found that prior knowledge of content could compensate for deficiencies in reading skill requiring the recall and summarization of text. Roe (1987) pointed out that the difficulty may arise because some poor readers do not realize they can use information that is not contained in the text. Likewise, prior knowledge of content does not compensate for difficulty with vocabulary (Stahl & Jacobson, 1986). Student interest in a topic bears no association to the student's prior knowledge about that topic; measures of interest and prior knowledge are virtually uncorrelated (Baldwin, Peleg-Bruckner, & McClintock, 1985). Strategies related to science reading are action plans, methods, or a series of maneuvers that reflect the characteristics and demands of the task and the textual materials. Strategies,

unlike traditional skills, involve clusters of bottom-up and top-down skills purposefully integrated to achieve a specified goal (Pressley, Goodchild, Fleet, Zajchowski & Evans, 1989; Lysynchuk, Pressley, d'Ailly, Smith & Cake, 1989). Strategies frequently involve accessing and decoding skills linked with decision-making skills and communication skills.

Dole, Duffy, Roehler, and Pearson (1991), Paris (1987), and Pressley, Johnson, Symons, McGoldrick, and Kurita (1989) identified several strategies that are critical to reading, which are frequently missing in ineffective readers but which respond to instruction. They include:

1. Assessing the importance of text-based information and prior knowledge.
2. Generating questions to set purpose.
3. Summarizing.
4. Inferring meaning.
5. Monitoring comprehension.
6. Utilizing text structure.
7. Reading and reasoning critically.
8. Improving memory.
9. Self-regulating to fix-up comprehension failures.
10. Skimming, elaborating and sequencing.

Older and better readers conceptualize reading and use these strategies differently from younger and less able readers. L. Baker (1991) pointed out that able readers recognize that reading is about understanding, changing strategies to match purpose, utilizing various standards to evaluate

comprehension, and applying different strategies to fix-up comprehension failures. Effective readers have considerable knowledge about the reading process and personally regulate their purpose, effort, and approach while they are reading.

Kletzien (1991) compared the strategies used by good and poor readers in dealing with historical texts at the independent, instructional, and frustration levels. She identified seven strategies used by these readers and found that the specific application and frequency of use varied with text difficulty. Good readers use more types of strategies than do poor readers. Increased text difficulty reduces the number of strategies used, while the type of strategy used changes with text difficulty; i.e., visualization with independent level text, text structures with instructional level text, and vocabulary strategies with frustration level text.

The existence of relevant conceptual knowledge and appropriate reading strategies do not ensure comprehension. The reader's awareness of the cognitive process and the selection and control of knowledge and strategies are also necessary. Metacognition is a fuzzy but critical construct.

Paris, Wasik, and Van der Westhuizen (1988) suggested that many children, particularly poorer readers, do not use effective strategies for monitoring their reading performance. They stated that "poor readers have developed an orientation to reading as decoding and word processing rather than meaning construction" (p. 149). They argued that poor reading performance may be due to inadequate knowledge, practice, or

motivation regarding the use of reading strategies. Otero and Campanario (1990) stated that:

> A serious problem for younger students is not only understanding the texts but calibrating their comprehension: believing that they understand when in fact this is not so. (p. 457)

Armbruster and Brown (1984) suggested that self-appraisal or knowledge about cognition and self-management or regulation of cognition include four complementary functions:

1. Planning one's next move.
2. Checking the outcomes of any strategies one might use.
3. Monitoring the effectiveness of any attempted action.
4. Testing, revising and evaluating one's strategies for learning. (p. 274)

Palincsar and Brown (1984) described six comprehension-fostering and comprehension-monitoring functions that are thought to be under the reader's strategic control. These include:

1. Understanding the purposes of reading, both explicit and implicit.
2. Activating relevant background knowledge.
3. Allocating attention ... [focus on major content].
4. Critical evaluation of content for internal consistency, and compatibility with prior knowledge and common sense.

5. Monitoring ongoing activities to see if comprehension is occurring, by engaging in such activities as periodic review and self-interrogation.
6. Drawing and testing inferences of many kinds, including interpretations, predictions, and conclusions. (p. 120)

Palincsar and Brown (1986) indicated that the second function, activating relevant background knowledge or the reader's schema, is an integral part of all of the other functions. The critical role of prior knowledge, along with interest, was found to significantly affect reading comprehension and science learning (Guzzetti 1984: Zeitoun, 1989).

Textbooks in Science Teaching

Despite the emphasis on learning by doing in curricula developed under programs funded by the National Science Foundation during the 1960s, science teaching is still essentially dominated by science textbooks (Science Council of Canada, 1984; Ratekin, Simpson, Alvermann & Dishner, 1985). A study of classroom teaching by Barr (1987) suggested that textbooks, and other curricular materials, exert their influence in several ways: (a) as an organizing rubric, dictating scope and sequence for the study of content in the classroom; (b) as a determinant of classroom interaction, for instance, facilitating or enhancing the instructional process when materials are matched to student needs and abilities; and (c) as the dominant agent in establishing the actual content to be taught. Although Yore (1991) did not find actual use of textbooks in secondary school classrooms, the textbooks still influenced topic coverage,

conceptual sequence, and instructional planning. Armbruster, Anderson, Armstrong, Wise, Janisch, and Meyer (1991) found that in grade four classrooms where science textbooks were used, students did little silent reading. Instead, reading was oral with teachers asking many questions, though few of these were taken from the textbook.

Studies in Canada and the United States consistently show that students lack basic skills and strategies for reading content texts and that science texts present particular problems to younger readers (Alvermann, Smith & Readance, 1985; Mayer, 1983; Stahl & Jacobson, 1986; Williams & Yore, 1985; Wixson, 1987). Reader deficiencies perpetuate a situation of dependency on the teacher for interpreting content texts. In a naturalistic study of teaching at both junior and senior secondary school levels, Ratekin, et al. (1985) found that science teachers use lecture or recitation about half of the instructional time and that they they rarely use more than one textbook. Not surprisingly, they also observed that teachers almost never expect students to learn concepts by independently reading the text. They stated that:

> Teachers used the single textbook with the single assignment for all students. They also used textbooks as a written verification - a safety net of sorts - for information presented via lecture and lecture-discussion. (p. 435)

Yore and Denning (1989) found that teachers substituted copying teacher-revised textual materials from the chalkboard

for reading science textbooks. It appeared as if teachers believed that the revised text was an improvement over the original text, equating verbatim copying with reading comprehension.

In a similar vein, an ethnographic study of reading in the classroom by Smith and Feathers (1983a; 1983b) suggested that most students view the teacher as the primary source of information. Further, students perceive course goals as being driven by an emphasis on facts, while, paradoxically, their teachers reported that course goals were focused on higher order thinking skills and knowledge. Student perceptions were confirmed by classroom observations in the study. Smith and Feathers noted that:

1. Most reading assignments were taken directly from the textbooks, with few outside references being consulted.
2. Few pre-reading strategies were employed in the classroom.
3. Worksheets were commonly employed to focus student attention on relevant text information.
4. Discussion of worksheet questions was the primary post-reading activity observed.
5. Most of the questions were at the literal or text explicit level with little, if any, higher level processing of text required by students.

6. Students did not feel obligated to read text assignments because the teacher would explain the material anyway.

Although this study was conducted in social studies classrooms, the findings are similar to those found in today's science classrooms in which teachers are the gate-keepers of print information (Shymansky, Yore & Good, 1991; Yore & Denning, 1989; Yore, 1991). Renner, Abraham, Grzybowski, and Marek (1990) have criticized the way textbooks are used in the science classroom, concluding that "the teacher can no longer adopt a textbook and follow it straight through" (p. 52).

Many teachers and researchers blame the textbook for student dependence on teacher explanations. However, perceptions of the problem differ. On the one hand, teachers mainly fault the readability of the text. Studies by Williams and Yore (1985) and Wood and Wood (1988) support this view. Although readability may be a part of the problem, science researchers have generally faulted other aspects of textbooks: style, interest level, inconsiderate texts, or the way textbooks are utilized in the classroom. Considerate text is usually explicit in its logical development: main idea sentences are evident and important ideas are fully developed, while irrelevant ideas are kept to a minimum. Tregaskes and Daines (1989) showed that most paragraphs sampled in elementary and middle school social studies textbooks did not open with an explicit main idea sentence, which is inconsiderate of novice readers.

However, in their study Meyer, Crummey, and Greer (1988) concluded that most science text passages analyzed were considerate. Ulerick (1989) framed that problem differently, however, stating that science textbooks:

> are written in an impersonal, seemingly objective tone, which ignores the readers' needs. ... Textbook authors write as if the reader has as much prior knowledge as they do; and they assume that readers are familiar with the style and structure of expository writing. (p.1)

Guri-Rozenblit (1989) observed that "expository texts often provide too few links between facts, and between facts and main ideas," forcing readers to construct meaning piecemeal from inconsiderate text. Lloyd (1990) argued that although readability and considerateness may be valid constructs, they still do not fully explain the difficulty of science textbooks. He suggested that the extent to which major concepts are elaborated in a text — embellishments that provide meaningful supporting details or extend the major ideas — may be just as important in determining its difficulty. Lloyd stated that "unelaborated ideas ... increase the content density of a text" (p. 1029). This means that publishers may inadvertently increase the difficulty of a textbook by relying exclusively on readability indices that disregard connectiveness and elaboration.

Holliday (1985) identified eight research-based dimensions that can be used in studying science textbooks. Among these dimensions are included semantic and syntactical

factors, clarity, unity, coherence, graphics, and other adjunct devices like questions and analogies. In one study, Strube (1989) analyzed selected physics texts, characterizing the language as formal, rigid, cold, impersonal, and overly concerned with precision and logical argument. He noted that the syntax was limited, with short sentences for definitions, and long convoluted sentences for explanations. For students who have been weaned on narratives, the transition to expositive science textbooks may be difficult.

Science textbooks may be simply reflecting the characteristics associated with scientific expository text. Bulman (1985) suggested that scientific writing includes many scientific terms, very complex sentence structures, many qualifying words and phrases, a large variety of verb forms and tenses (the passive voice for reporting experiments, nominalization for giving directions or for describing scientific laws, and modal verbs like *might*, *could*, *may*, and *should* for giving precise meaning), and a style that is impersonal. Ebel, Bliefert, and Russey (1987) stated that these characteristics give science a cloak of objectivity by converting generalized language into highly specific meaning. White and Tisher (1986) suggested that students do not always appreciate the subtleties associated with these linguistic nuances. They reported that "connectives indicating inference, such as *therefore*, and qualified generalizations, such as *often* and *in general* cause undue difficulties for many students" (p. 882). These characteristics pose many obstacles that must be

overcome by the novice reader in the process of constructing meaning. Simmons, Griffin, and Kameenui (1988) observed that:

> Students who possess sufficient prior knowledge of the content, exhibit adequate word recognition and vocabulary skills, and are 'text-wise' may find learning content-area expository prose a manageable task. (p. 15)

However, those students lacking adequate world knowledge and essential reading skills inevitably experience frustration when confronted with this difficult task. Furthermore, whether familiar material is placed before or after unfamiliar material does not appear to matter to readers with low prior knowledge; but if familiar material is placed first when read by those with high prior knowledge, it may actually interfere with the acquisition of new material (Davey & Kapinus, 1985).

Holliday (1986) identified rules for designing effective science text, specifically:

1. The organization and contents of a text should reflect the author's concept of science and inspire the student to learn.
2. Headings and pointer words should be reliable signals of a predictable organization.
3. Selected words and sentences representing new science information and requiring special study should be highlighted using bold-type, italics, color, underlining, or some other graphic technique.

4. A science text should be coherent and avoid clutter — i.e., unnecessary modifiers, jargon, and vaguely referenced words and phrases.
5. New science information should be explained and should connect to old information.
6. Extraneous, distracting information should be placed in tables, figures, boxes, or simply deleted.
7. Visuals and other graphic devices should be referenced in the prose, in addition to being appealing. They should be used to highlight important science information, and to clarify semantic positions among science concepts in the layout.
8. Study questions and problems should encourage implicit comprehension of important science information and clarification of the author's purpose, rather than explicit and rote processing of information.
9. The author should describe how to study a science text by providing direct instruction of strategies with examples and suitable exercises on how to learn.

Roth (1991) recommended that authors outline the epistemological development of the concept, providing a synthesis of the evidence supporting current beliefs. She believes that students need to appreciate the struggle among alternative explanations of evidence and that the text needs to

challenge the reader's misconceptions, while providing compelling reasons for accepting revised conceptions. Furthermore, connections should be developed between concepts, as well as between concepts and relevant real-world applications.

Nonetheless, perfect textbooks may be impossible; even if they did exist, their use by students in science classrooms might not be radically improved. As Wandersee (1988) suggested:

> Teachers think that if science content is accurate, up to date, and presented in a lively manner, learning will occur. Researchers, however, disagree, saying the assumption that students will comprehend fully an attractive and accurate text just by starting at the beginning and reading through to the end needs to be challenged. (p. 69)

Sawyer (1991) reviewed the research on texts designed to inform and instruct readers. She found few studies justifying many practices and beliefs about readability, text features, inherent interest of texts, revision strategies, and reader-devised comprehension strategies. Interactions between text features, reader attributes, content, context, and measures of comprehension were all too common. She concluded that:

1. Readability indices have limited applicability for instructional text.

2. Text structure research is limited by its focus on recall rather than understanding.
3. Expert revision is inconsistent and disregards the instructional context.
4. Research regarding the interest level of text is limited by instability of the construct and reliance on recall measures.
5. Reader-devised comprehension strategies have revealed the promise of instantiated scenarios.

DiGisi (1990) reviewed studies of scientific and technological content text from grade six to college level that purported to improve comprehension. She found that few features and strategies were substantiated by the selected studies. Applying her synthesis of research to assess high school biology textbooks and teacher editions revealed that textbooks features and strategies were justified by current research, but that teacher editions provided little guidance in the effective use of the text or in the kind of instruction that would be compatible with them.

Based on the interactive-constructive reading model and established research results, it would appear to be unproductive to simply focus on the nature of science text alone to improve reading comprehension in the content areas. Palincsar and Brown (1984) suggested that comprehension is determined by three main factors:

(1) considerate texts; (2) the compatibility of the reader's knowledge with text content; and (3) the active strategies the

reader employs to enhance understanding and retention, and to circumvent comprehension failures (p. 118).

Even if textbooks could be rapidly overhauled to address these considerations, it perhaps would be more productive to focus on the reader since so much scientific knowledge is stored in less considerate text. Yore and Shymansky (1991) stressed that science text must be viewed as a single component in the construction of science understanding. The text-driven, bottom-up model of reading, which dominated the research of the 1950s-60s, exaggerated the importance of text and decoding skills while discounting the reader's prior knowledge and situational context. The contemporary interactive-constructive model of reading balances the importance of text, reader, and context. This model reorients the research emphasis away from simply manipulating textual features and isolated skills toward prior knowledge, meaning-making strategies, contextual support, related information sources, and knowledge about and control of the construction process.

Comprehension Instruction

Comprehension instruction is concerned with enhancing the reader-text-context connections that facilitate improved understanding. The interactive-constructive reading model suggests that comprehension instruction should consider both interactive and constructive dimensions, such as decoding skills, strategies, prior knowledge networks, and awareness and control (Flood, 1984). Comprehension instruction

regarding expositive tex should be an integral part of classroom instruction if teachers are to accommodate the range of abilities, background, and textual demands (Singer & Donlan, 1989).

Brown, Campione, and Day (1981) suggested that reading comprehension instruction is often simply blind training, with uninformed students mechanically following procedures without reflecting on the activity. Armbruster and Brown (1984) later advocated an approach to reading comprehension involving cognitive training with awareness.

Tierney and Cunningham (1984) reviewed research on comprehension instruction and categorized the various studies into two groups according to the instructional goal underlying each one. The goal of studies in the first group was "increasing comprehension from text," while the goal of the second was "increasing ability to comprehend from text" (p. 609). Although the distinction between the two groups appears superficial, it has a strong impact on the way research is conducted, its questions, its methods, and its conclusions. The first group is actually concerned with the study of teaching strategies, or the effectiveness of teacher interventions, while the second group focused primarily on the study of learning strategies, which implies that the specific or general abilities acquired by the student in the instructional phase should be generalizeable to new situations. The two groups also differ in that the locus of control is eventually vested exclusively in the student in the second group. Teachers appear reluctant to

relinquish control in the classroom, emphasizing teaching rather than learning strategies. Johnston (1985) argued that "teachers need to be concerned about improving children's comprehension ability rather than just their comprehension" (p. 643).

Pressley and Harris (1990) suggested that effective strategies designed to improve students' comprehension are currently available, but that professional opinions do not always reflect the existing research base. Rich and Pressley (1990) found that comprehension strategies instruction was not well understood or accepted by classroom teachers. Much of this problem is due to the lack of dissemination of empirically supported approaches and the lack of understanding of the interactive-constructive model of reading (Shymansky, Yore & Good, 1991; Yore, 1991; Yore & Shymansky, 1991).

Haller, Child, and Walberg's (1988) synthesis of metacognitive studies revealed a large average effect size. They found that (1) more recent studies yielded larger effects, (2) urban students did better than rural or suburban students, (3) the largest effects were with grades seven and eight students, and that (4) some strategies were more effective than others.

Pressley, Goodchild et al. (1989) described some caveats that should be considered when reviewing studies of comprehension instruction. First, this research area is subject to aptitude-treatment-interactions, which might mean that

low-ability students respond to treatment better than high-ability students, or conversely that high-ability students respond better to treatment in other instances. Second, they suggested that whether or not a particular student benefits from some types of strategy instruction may really depend on the individual's short-term memory. This point is grounded in research by Kintsch and van Dijk (1978), which suggested that individuals process a text in chunks of seven plus or minus two propositions at a time. The size of working memory and the cognitive demands of science text thus limit the space available for decoding and integrating text (Britton, Glynn & Smith, 1985). Third, they warned that "most strategy-instruction interventions are offered with either no evaluation or very superficial testing" (p. 320). Teacher journals and newsletters, and even content area reading textbooks, may make claims about the effectiveness of particular instructional strategies without adequate proof or supporting evidence (Alvermann & Swafford, 1989).

Lysynchuk, et al. (1989) reviewed 34 experimental studies of comprehension strategy instruction, evaluating the methodological adequacy of each one according to standards of internal and external validity. Internal validity minimizes the possibility that alternate interpretations for the data in a study can be justified, while external validity is concerned with generalizing the study's findings to other similar situations. The 24 criteria for internal validity that were studied can be categorized under four general headings: general design,

possible confounds, measurement, and statistics. They concluded that:

> Researchers should give especially high priority to assigning subjects randomly to conditions and eliminating confounds. More extensive pilot testing is also critical to decrease the probabilities of ceiling and floor effects and to provide researchers with complementary process measures that could be helpful in specifying how the treatment produces its effects. (p. 466)

According to the six criteria of external validity, the most predominant shortcomings among the 34 studies reviewed included failures to adequately study the issues of maintenance and transfer of the strategy instruction. Maintenance is concerned with the durability of strategy instruction, while transfer assesses whether or not the strategy is effective on tasks that are different but related to the experimental measures within a subject domain. Overall, the 34 studies reviewed violated one-third of the criteria for external validity and one-quarter of the criteria for internal validity.

In a review of explicit comprehension instruction research, Pearson and Dole (1987) expressed a number of concerns about the application of experimental findings to the classroom. First, despite research findings suggesting that explicit instruction improves reader comprehension, the issue of whether or not performance is generalizable to other content domains is still unresolved. The issue here is whether or not

strategies acquired in a particular intervention study in social studies would be equally useful in other areas like science and mathematics. They proposed an instructional strategy that establishes need, models desired outcome, provides directed practice and consolidation, and encourages transfer of ownership and application. Fields (1990) suggested that explicit comprehension instruction should be embedded in real reading tasks, which provide explanation and rationale, model problem-solving aspects of strategic reading, and utilize think-alouds.

Despite significant increases in dependent variable measures, students have not always improved on standardized measures of comprehension. This anomaly has not been adequately addressed by researchers in the field. Tregaskes and Daines (1989) argued that Cloze tests and Error Detection tests may be more reliable measures of comprehension than standard comprehension tests. Further, Paris, Wasik, and Van der Westhuizen (1988) stated that the Gates-McGinitie test, which has commonly been used as a measure of reading comprehension, may actually "assess fluent decoding, vocabulary, and background knowledge more than metacognition or strategic reading" (p. 149). Many studies have employed free recall as a dependent measure of reading comprehension. Since free recall is based on the total number of ideas recalled without any consideration of their relative importance or connectiveness, one might question its adequacy in measuring science comprehension, given that meaningful

learning is generally recognized as the primary goal of science education.

Carver (1987) argued that measured improvements in reading comprehension can be misleading and may instead be attributed to other effects. He described four principles that should be considered when interpreting the results of studies of comprehension instruction:

1. The Easiness Principle suggests that the reader's interaction with the difficulty of the passage may sometimes account for improvements in comprehension.
2. The Reading Time Principle suggests that the treatment group may have improved simply because they spent more time reading the materials.
3. The Practice Principle suggests that the treatment group may have honed their skills on the particular task used as a dependent measure, and consequently improved with simple practice.
4. The Prior Knowledge Principle suggests that students will show better comprehension if they have prior knowledge of the domain under study.

These four confounding principles may explain why there is not always transfer of a "comprehension strategy to general reading ability" (p. 117). Carver argued that spending more time to increase comprehension, p rticularly when recall is the dependent measure, should realistically be considered a study

skill in disguise, rather than as comprehension. In addition, he emphasized the importance of reporting the readability of text passages, as well as the reading abilities of the subjects. Without this basic information, it is difficult to assess the metacognitive dimension in the studies.

The distinction between comprehension and study merits further attention. Anderson and Armbruster (1984) stated that, "studying is a special form of reading;" it differs from reading in that it is specifically cued in "preparation for performing a criterion task" (pp. 657-658). Research in this area has focused on both the encoding processes used in dealing with textual materials and the retrieval processes in performing the criterion task. Some of the techniques that have been studied include underlining, note taking, summarizing, outlining, elaborating, and representing text diagrammatically. Elaboration involves relating unfamiliar material to prior knowledge through mental images or verbal elaborations, for instance by using analogies. Representing text diagrammatically involves procedures for "visually representing the important relationships among ideas in text. ... for transforming linear prose into nonlinear symbolic representations" (p. 673). The line separating reading comprehension and studying is faint, but it must nonetheless be kept in mind when reviewing comprehension instruction research.

Paris, Wasik, and Van der Westhuizen (1988) reviewed research on metacognition and reading. They described some

of the potential problems and pitfalls associated with studies of metacognition and reading:

1. Can time on task account for the improvement in comprehension?
2. Have measures of student metacognition before and after treatment been included?
3. Have Hawthorne effects been adequately controlled?
4. Can differential student motivation account for differences?
5. Has teacher knowledge about metacognition been reported?
6. Can the study's findings be applied to other students and other classrooms?

The authors also described some difficulties associated with the measurement of metacognition (also see Yore & Craig, 1990). For instance, verbal reports and think-aloud protocols are inherently difficult for children (verbal facility, forgetting, etc.) and provide only tenuous evidence due to the possibility of distortions and fabrications, while questionnaires primarily assess recognition and may limit the subject's opportunities for expression (Valencia, Stallman, Commeyras, Pearson & Hartman, 1991).

Other problems regarding what to teach and how to teach plague metacognitive interventions. First, the issue of exactly what to teach is not always straightforward. Metacognition involves declarative knowledge (the WHAT), procedural knowledge (the HOW), and conditional knowledge (the WHEN

and the WHY) about the reading strategies, as well as self-management of the reading process.

Second, "many training studies may be insensitive to individual levels of skill, knowledge, and motivation despite evidence showing that individual students vary considerably in these personal attributes (Paris, Wasik & Van der Westhuizen, 1988, p. 32). Ecological validity still haunts the field of metacognitive research since many studies are decontextualized from regular classrooms, do not consider a variety of classrooms, or have been performed with a very small number of students. Pragmatic considerations of professional development may be the ultimate obstacle to successfully implementing the metacognitive research findings.

Dole, Duffy, et al. (1991) summarized reading comprehension research based on a strategic interactive-constructive perspective. They identified five strategies substantiated by research: (1) determining importance, (2) summarizing information, (3) drawing inferences, (4) generating questions, and (5) monitoring comprehension. They recommended an instructional framework based on the following principles:

1. Reading is a process of emerging expertise.
2. Reading strategies are adaptable and intentional.
3. Reading instruction is adaptable and intentional.
4. Reading instruction involves careful scaffolding.
5. Reading and reading instruction are highly interactive and reciprocal.

Paris, Wasik, and Turner (1991) supported both the strategies-based approach and the five general guidelines for instruction.

Based on these general research results, several strategies or dimensions show considerable promise for metacognitively based science reading comprehension instruction. The nature of science, science text, science reading, and science learning support the exploration of (1) prior knowledge, (2) text structure, (3) questions, (4) discussion, and (5) conceptual development.

Prior Knowledge

Prior knowledge, its organization, its accessibility, and its compatibility with new information are critical in science learning and science reading (Hynd, Qian, Ridgeway & Pickle, 1991; Zeitoun, 1989). Sawyer (1991) and White and Tisher (1986) reported that prior knowledge may be the critical factor in determining the effectiveness of advance organizers as a preinstructional strategy. Students lacking the appropriate background knowledge apparently benefit from advance organizers, while knowledgeable students do not. The existence or activation of prior knowledge, alone, does not ensure improved comprehension. The difficulties in effecting conceptual change and the interactions between prior knowledge and reading strategies have been reported in the literature.

Roller (1990) stated that research on the role of prior knowledge in the reading process has been conducted along three fronts:

1. By manipulating the knowledge variable only.
2. By simultaneously manipulating knowledge and text variables.
3. By observing performance when the text conflicts with reader knowledge.

Hansen (1981) investigated the use of a prereading strategy involving inference training on children's ability to predict events in a story. The inference training was found to be effective in teaching children how to utilize prior knowledge in making predictions. Langer (1984) investigated the relationships between prior knowledge about a specific topic and reading comprehension. The study involved using key words, or superordinate concepts, from the reading material to elaborate the students' existing knowledge in a brainstorming session prior to reading. This prereading strategy improved the comprehension of all but the poorest readers.

Afflerbach (1990) investigated the role of prior knowledge on reader summarization strategies. Readers with prior knowledge of the content in the study passage were able to automatically construct a main idea statement, while readers lacking the appropriate prior knowledge depended on different strategies in their attempts to isolate the main idea.

Flood, Mathison, Lapp, and Singer (1989) investigated the effects of introductory lectures on comprehension. Students who received a text-related lecture before reading comprehended significantly better than the control group. Stahl, Jacobson, Davis, and Davis (1989) investigated the effects

of relevant preteaching on compensatory interactions between vocabulary difficulty and prior knowledge. The findings suggested that vocabulary difficulty and preteaching operate independently with vocabulary difficulty affecting microprocessing (words and sentences) and preteaching affecting macroprocessing (gist).

Dole, Valencia, Greer, and Wardrop (1991) explored the influence of prereading strategies on the comprehension of narrative and expositive text. They found that a teacher-directed presentation was more effective than a teacher-guided discussion on immediate passage-specific comprehension, while both were more effective than no prereading strategy at all.

Alvermann and Hague (1989) investigated the effect of prereading activities on student learning from counter-intuitive text. Students with misconceptions about Newtonian physics were selected for this study. The study involved a two by three research design with text structure (refutation/nonrefutation) and activation (augmented activation/activation/control) as the independent variables. The refutation text specifically addressed the misconception, while the nonrefutation text presented relevant information without specifically addressing the misconception. Activation involved a science activity on the physics of motion, while augmented activation combined the activity with a written notice advising students to look for observations that might

conflict with their beliefs about motion. Alvermann and Hague concluded that:

> Students will comprehend counter-intuitive science text better when they have their misconceptions activated and then are told to pay attention to ideas that might conflict with their prior knowledge than when they have their misconceptions activated only. (p. 201)

Other studies have addressed the conceptual change issue relative to these discrepancies between prior knowledge and the information presented (Alvermann & Hynd, 1989a, 1989b; Hynd & Alvermann, 1989; Maria & McGinitie, 1987).

Roth, Smith and Anderson (1984), Anderson (1987), Anderson and Smith (1987) and Hynd, et al. (1991) described conceptual change strategies for addressing discrepancies between prior knowledge and current information. Each strategy relies heavily on engaging prior knowledge, predicting, verifying, restructuring, and elaborating. Without a teacher-guided instructional scaffolding that confronts conceptual differences, encourages integration of old and new information and facilitates restructuring of knowledge networks, students will selectively process new information to support their present conceptions or, alternatively, will develop dual conceptions.

Text Structure

Expositive text utilizes a variety of text features, language forms, linguistic techniques, adjuncts, aids, and structures to help convey meaning and limit interpretations.

Much of what students know about text has been derived from their experience with narrative text that utilized a relatively consistent story grammar (setting, beginning, development, ending), supported by illustrations and chapter titles. Scientific text commonly utilizes five expositive structures (description, listing, compare/contrast, problem/solution, cause/effect), content specific language, visual adjuncts (pictures, diagrams, graphs, charts, tables), mathematical symbols, heading/sub-headings, and linguistic signals.

Armbruster (1991) believes that part of the difficulty students have with expositive text is due to their lack of instruction in how to read expositive text which is further exacerbated by their lack of experience with it. Roller (1990) stated that:

> Readers do use their knowledge of text structure to construct their interpretation of the text. ... Text structure thus lies somewhere in the interaction between reader and the text. (p. 81)

Kintsch and Yarbrough (1982) found that improved reading comprehension and identification of main idea were supported by familiar rhetorical structure.

Taylor and Beach (1984) investigated the use of summarization as a study strategy in the comprehension and production of expository text. The experimental group in this study received hierarchical summarization training, which involved a basic protocol: selecting the central idea for the entire passage, then the main idea for each section followed by

several supporting details. The results suggested that hierarchical summarization training enhanced the recall of unfamiliar material. The authors believed that readers did not require such a strategy to get the gist of the text with relatively familiar textual material because the reader's conceptual schema was able to accommodate the information without difficulty. However, unfamiliar material required the reader to consciously use the summarization method to process the information efficiently.

Berkowitz (1986) investigated the effectiveness of using graphic representations of text structure, or maps, to improve text recall. A map was defined as "a graphical representation of the superordinate and some of the more important subordinate ideas in a passage" (p. 165).
The study indicated that map-construction procedures enhance student recall of expository text. Ruddell and Boyle (1989) investigated the effect of mapping on comprehension and written composition. Expository passages representing different rhetorical structures were used in this study. Dependent measures included holistic scores on essays, the use of cohesive ties (different types of conjunctions), and frequency of main ideas and supporting details. The study showed that students who used maps had higher scores on their essays, while also using significantly more cohesive ties and including more supporting detail. The use of graphic representation for each of the expositive text structures also appears to improve achievement (Armbruster, Anderson &

Meyer, 1991; Armbruster, Anderson & Ostertag, 1987). Gordon and Rennie (1987) used discussion of teacher-made semantic maps to achieve conceptual change in students. Novak and Gowin (1984) and Wandersee (1988) encouraged the use of concept circles, concept maps, and Vee-maps to increase meaningful learning.

Hare, Rabinowitz, and Schieble (1989) investigated the effect of several text structure variables on main idea comprehension. Two separate but complementary studies assessed comprehension: (1) relative to the sentence position of the main idea within a listing structure, and (2) when the main idea was either explicit or implicit within one of four different rhetorical structures. The studies showed that students had more difficulty in identifying the main idea when it was not in the initial sentence position, when it was implicit in the text, and when the text structures were comparison/contrast or cause/effect. The authors concluded that students who have been taught to identify main ideas using only contrived texts, such as those found in basal readers, will have difficulty transferring those strategies to naturally occurring texts.

Graves, Prenn, Earle, Thompson, Johnson, and Slater (1991) explored the influence of revision of history text by writers from various perspectives (linguist, composition instructor, Time-Life writer) on reader comprehension. This study refuted the Graves, Slater, Roen, Redd-Boyd, Duin, Furniss, and Haseltine (1988) results and supported the

Britton, VanDusen, Guloz, and Glynn (1989) and Duffy, Haugen, Higgins, McCaffrey, Mehlenbacher, Burnett, Cochran, Sloane, Wallace, Smith, and Hill (1989) results. Overall, the findings indicated that reader comprehension and attitudes towards the composition instructors' revisions were significantly improved, not only over the original edition but also over the revisions proposed by the linguists and the professional writers. Some of the revision strategies used in this study may have limited application to scientific text.

Sawyer (1991) summarized the research on text structure, text revision, and comprehension. She suggested that the potential influences of text structure and revision strategy on comprehension appear to lie outside the text within the reader. Readers' prior knowledge, readers' attitudes, and measures of comprehension interact with text structure, textual adjuncts, and composition style to influence comprehension. Sawyer cautioned content area researchers about generalizing from narrative to expositive text research. She stated:

> Good instructional texts are more than readable and more than recallable. A good instructional text should be studyable; that is, it should stimulate interest in and critical examination of its subject. (p. 319)

Research to improve comprehension instruction needs to consider texts in a classroom setting, reader-text-context interactions, discipline-specific attributes, and prior knowledge-text interactions (Roller, 1990). Text structure

variables exert a pronounced effect on comprehension when the text is moderately unfamiliar to the reader. Roller suggested that text structure is not useful to the reader when confronted by a very difficult text since it is probably beyond the reader's cognitive abilities. Conversely, when text is easy, text structure procedural knowledge would not be required since the reader's conceptual schema can easily accommodate the information (Kletzien, 1991).

Questions

Questions continue to have promise as one of the most frequently used teaching tools, but they lack substantive support in the science comprehension research literature. The role of questions in comprehension instruction can be analyzed under different rubrics: adjunct questions, teacher questions during classroom discourse, and student-generated questions in response to texts. Adjunct questions may take the form of questions inserted in textual material that are to be answered before, during, or after reading. Adjunct questions have been the object of considerable research in comprehension instruction, but further research is still required to establish their effectiveness across different types of texts, different content and different readers (Tierney & Cunningham, 1984).

Shepardson and Pizzini (1991) analyzed the textual questions in three popular junior high school science series and classified their cognitive level as input, processing, or output. Input questions require the reader to recall information. Processing questions require the reader to establish

relationships amongst recalled information, while output questions require the reader to creatively transform the information. They found no significant differences in the proportion of input, processing and output questions across textbook series, science disciplines, or chapters. They did find significant differences in the proportion of input questions compared to processing and output questions. Shepardson and Pizzini stated:

> Since comprehension ... involves extracting and integrating textual information with prior knowledge, an overabundance of input-level questions ... [may] inhibit the students' cognitive level of interaction with the textual information, ... [and may limit the likelihood] that the textual information will be integrated [into the readers' schemata]. (p. 679)

Questions used to promote and evaluate science learning must be aligned with the stated learning outcomes and the interactive-constructive learning model.

DiGisi (1990) summarized the research on questions in junior high school to college-level biology texts and found the results mixed, depending on question placement, reader characteristics, and measures of comprehension. She reported that prequestions were not uniformly effective, focusing comprehension mainly on explicit recall (Leonard, 1987; Spring, Sassenrath & Ketellapper, 1986). DiGisi found no support for interspersed questions, but several studies did support the use of postquestions. Raphael and Gavelek (1984)

suggested that the effectiveness of postquestions is conditional, depending on the age and ability of the target students. Meaningful learning questions, those requiring high cognitive processing like application, analysis, synthesis and evaluation, facilitate intentional learning, while explicit questions facilitate only rote recall (Sawyer, 1991). Adjunct questions can also facilitate learning from charts, graphs, and other text figures and illustrations. Holliday and Benson (1991) were able to demonstrate that "adjunct questions interacted with science charts ... powerfully" to improve learning (p. 108).

Raphael and Gavelek (1984) suggested three reasons to explain the importance of questioning activities in the classroom. First, teacher questions can focus student attention on important concepts and details to be learned. Frequently, the misalignment between lesson goals and teacher questioning conveys conflicting messages to students. Second, teacher questions can enhance learning when used to review important ideas or to clarify and consolidate subtle relationships among the concepts. Hynd, et al. (1991) believed that teacher questioning is necessary to remediate student misconceptions. Third, reader-generated questions can enhance comprehension by forcing readers to evaluate their learning of textual information.

Reader-generated questions enhance the comprehension of textual materials in two ways. First, the use of prospective questions encourages the reader to make predictions about a text prior to reading. The essential mechanisms at work here

would be activating the reader's schema and setting a purpose for reading. This process facilitates the integration of textual information with the reader's prior knowledge. Second, reflective self-questioning allows the reader to constantly monitor comprehension, to detect comprehension success or failure, and to regulate comprehension strategies appropriately.

Pearson (1991) explored the influence of teacher-generated questions and reader-generated questions on science comprehension. The results indicate that self-questioning was beneficial to the low-reading group. Wong (1985) suggested that it may not be the questions generated by the reader so much as the cognitive processes required to implement the self-questioning activity.

Pearson and Johnson (1978) classified questions according to whether they were text-explicit, text-implicit, or script-implicit. On the one hand, explicit questions require a literal interpretation of the text, while text-implicit questions require reader inferences from the text. Script-implicit questions, on the other hand, cannot be answered from the text alone. The reader must use prior knowledge, concurrent experience, and potential helpers, while extending, elaborating, or evaluating the text information to answer the script-implicit questions. Frequently, instructional science text, conceptual change, and meaningful learning all require implicit responses to construct new understandings.

Raphael and Gavelek (1984) reported on a study in which students were made aware of the question-answer relationships (QAR) evident in a text. High-ability students in the training group were no better than those in the control group on explicit questions. However, they were more successful on script-implicit questions. Both low and average ability students improved their performance on text-explicit and text-implicit questions, but made only minor improvements on script- implicit questions. One possible interpretation is that script-implicit questions require an important knowledge base (i.e., prior knowledge or world knowledge), that may be lacking in some students. They concluded that "questioning activities have the potential for generating both comprehension and metacomprehension of text materials" (p. 247).

Discussion

Raphael and Gavelek (1984) stated that teacher questioning patterns show a high proportion of text-based literal questions. This situation has a definite effect on classroom discussions. Armbruster, Anderson, Armstrong, et al. (1991) found that textbook questions play a minor role in guiding classroom discourse, with teachers relying heavily on their own questions. Studies suggest that classroom discourse is still firmly entrenched in the recitation tradition with the teacher initiating discussion through questioning, students responding to these questions, and finally the teacher evaluating student responses (Cazden, 1986). This pattern of

initiation-response-evaluation (I-R-E) utilizes questions as evaluative or control devices rather than as meaning-making adjuncts or as a cognitive scaffolding. O'Flahavan, Hartman, and Pearson (1988) examined the nature of teacher questioning, student response patterns, and teacher feedback practices in grades two, four and six. They noted changes in the dynamics of classroom discussion since an earlier 1967 study but concluded that many other characteristics of discussion remained essentially unchanged. They concluded that literal questions accounted for nearly a third of all questions, that teachers initiated and terminated a disproportionate amount of the classroom verbal interactions, and that teachers tended to monopolize the flow of discussion.

Alvermann, O'Brien, and Dillon (1990) conducted a naturalistic study of content area reading assignments using various qualitative methods including field notes, videotaped lessons, and structured interviews. They analyzed 24 classroom discussions and found only seven verbal interchanges that were true discussions or:

> ... open forums, in which students present multiple perspectives, interact with one another as well as with the teacher, and use discourse longer than the one- or two-word responses associated with recitation. (p. 308)

The balance of the discussions were classified as either recitation or lecture-recitation. All six science classes that were analyzed fell into these categories. They concluded that the type of discussion observed in class was consistent w th the

teacher's purpose. When the purpose involved defining terms, giving information, or reviewing content, recitation or recitation-discussion was frequently chosen. However, when the purpose involved facilitating comprehension, then the open forum type of discussion predominated. They noted a contradiction between teachers' intellectual definitions of discussion and the operational definitions derived from classroom observations.

Alvermann and Hayes (1989) conducted a six-month study in which they worked closely with five secondary teachers to improve classroom discussion of text materials. Each intervention began with an initial conference with the teacher to establish a common purpose, followed by classroom observations and an analysis of a videotaped lesson, then a planning conference to determine a plan of action for effecting change, and finally an analysis of the completed intervention. Additional data also were collected using field notes, student interviews, and questionnaires. They suggested that it is extremely difficult to change teacher verbal interaction patterns from the dominant recitation mode.

The study of classroom discourse, or teacher-student interactions, is important because it can clarify how the processes of learning or teaching actually evolve in the classroom. Such research should explore how teachers select knowledge to present to pupils, how they break up topics, how they sequence their presentation, how these discrete infobits are linked, how teachers utilize textbook questions, how

distinct topics are introduced and terminated, how students' responses to questions are evaluated, how students are made to reformulate their contributions, and how students use these infobits to reconstruct conceptual understandings or to integrate them into established schemata.

Teacher education institutions still transmit a rather static view of lesson planning to preservice teachers. Green and Weade (1987) argued that "lessons, while structured and goal directed, are not scripts to be followed by rote. Rather, lessons are dynamic, probabilistic phenomena that are created, not followed" (p. 30). Knowing how experienced teachers use textual materials in the classroom to teach certain concepts in science would be useful to novice teachers. Barr (1987) stated that "the essence of instruction can be captured through detailed study of instructional interaction" (p. 150). Since novice teachers are generally uncertain about how to teach particular concepts, research findings from naturalistic studies might serve as suitable guides for planning instruction and for identifying the content knowledge, the pedagogical knowledge, and the content pedagogical knowledge for science instruction using texts. Cazden (1986) indicated that few interpretive research studies have focused on the links between classroom discourse and school content.

Conceptual Development

White and Tisher (1986) stated that one of the major themes in current research is the learner's assimilation of science knowledge. Much of this knowledge is obtained by

students from science textbooks. The actual learning, however, may be mediated by the teacher through instructional decisions about textual materials, questions, and classroom discourse. For instance, the teacher's selection of textbooks and adjunct questions determines the content to be learned and establishes the depth of information processing expected of students. Teacher questioning can enhance students' learning by forcing them to confront, link, elaborate, extend, and delimit the concepts into a growing web of science knowledge. Bulman (1985) suggested that "science teachers, in general, have not used reading as a way of developing pupils' understanding of science" (p. 16). White and Tisher recommended more research on the role of the text in the science classroom.

Unfortunately, findings from comprehension instruction research in other content areas cannot always be readily adopted in the science classroom. Alvermann and Swafford (1989) suggested that some strategies, like advance organizers, revision, and text structure, appear to be less effective with science texts, compared with their use in other subjects, like social studies; while other strategies, like the three level guides, have not been used much with science texts. Science also has its own language, as well as being grounded in a philosophical tradition that is removed from the humanities and the social sciences. Yore (1986) suggested that:

> Few inferences from content reading research utilizing social studies or language arts can be comfortably applied to science and mathematics reading. Many research

> studies related to reading comprehension need to be replicated using science and mathematics textual materials before valid inferences or generalizations can be produced regarding text processing and comprehension of science. (p. 6)

Alvermann and Swafford concluded that comprehension strategies may vary in their effectiveness, depending on subject area and grade level.

Conceptual development utilizing scientific text is not fully mapped, but traditional text initiated learning is historically documented. Precisely what the reader did to successfully make sense of the scientific text is unknown. Knowledge acquisition and strategy development are not simple, quick, steady processes (Boyle & Maloney, 1991). Students are reluctant to reject personal conceptions and conceptual restructuring occurs in starts, stops, and reversals. Cognitive scientists have found that rule acquisition and strategy development follow a similar pattern. The cognitive flux associated with intellectual dissonance may result in negative learning before new ideas are fully accommodated and positive achievement is observed. The links amongst strategic knowledge, strategy management, and conceptual development require basic exploration. Comprehension instruction requires a long-term commitment if students are to apply the strategies necessary to reduce the demands of lower-order and memory management processes, and to maximize

higher-order processing like conceptual integration (Britton, et al. 1985).

Future Directions

Many critics of science textbooks, science reading, and comprehension instruction have combined very limited negative evidence on isolated decontextualized issues (readability, text structure, gender equity, abstractness, goals content alignment, classroom use, and teachers' attitudes and beliefs) to formulate a general opinion. D. Baker (1991) summarized the analysis of the 1989 science education research on textbooks and reading by stating:

> The research on textbook quality indicated that there is little good to say about an instructional tool that is relied on so heavily. ... Given this, it should not be surprising that textbooks or text-based instruction was less effective than other methods of instruction or that textbook-based instruction had to be augmented in some way to bring about significant learning. ... However, many researchers will argue that textbook-based instruction is the reality of schools. My response is that responsible science educators should not capitulate to a poor practice because it is the reality. They should continue to argue for good practice and conduct research that makes the implementation of that practice easier for teachers. (p. 367)

It is difficult to support such generalizations abstracted from a single year of science education research on textbooks and

reading. However, applied research cannot disregard the reality, the context, and the interactive-constructive nature of science reading. It would be foolhardy to ignore scientific textual materials and science reading comprehension in science education research and school programs, since so much of our scientific heritage — 6000 years of history — is stored in print. Scientific literacy would be less than comprehensive without the cognitive strategies to access and understand this legacy.

Considerable effort must be devoted to exploring the central issues of relating information sources, cognitive strategies, metacognition, and science learning. The relationships amongst self-appraisal knowledge, self-management, meaning-making, strategies, canons of evidence, and conceptual development in science are not well established. Future research could productively explore students' knowledge of reading and inquiry strategies, and science achievement based on multi-dimensional models of self-regulated learners in different contexts. Once these associations or relationships are established, comprehension instruction may be more meaningful and effective, or at least research will be more sharply focused.

The 1985-1991 literature reviewed clearly indicates that existing school programs do little to help students comprehend science text and that some comprehension strategies for expositive text respond positively to explicit instruction. A very small minority of students reports receiving any form of explicit comprehension instruction regarding expositive text. It

is reasonably safe to suggest, based on recent research results, that several metacognitive strategies would be sensitive to explicit instruction and might produce comprehension increases when embedded in the normal science program (Paris, Wasik & Turner, 1991; Pearson & Fielding, 1991; Yore & Shymansky, 1991). The integration of grade four reading instruction into a text-guided science program has revealed surprising gains for both reading and science achievement (Romance & Vitale, in press). Romance and Vitale have also found positive effects with the integrated science/reading program for at-risk students. The use of scientific textual materials to elaborate and extend experiential programs is logically defensible, mediating learner attributes when paired with explicit comprehension instruction (Yore, 1987). Future research must specifically address the comprehension of scientific text, the affective considerations underlying comprehension instruction, and the use of scientific textual materials in natural settings.

Barr (1986) criticized the predominance of experimental research in the study of classroom reading instruction. Without reiterating some of the points already raised by others, she suggested that experimental studies have failed to consider conditions that fundamentally characterize the instructional process. Variables like time constraints, characteristics of teachers and of learners, classroom management, and the social context have been disregarded in much of the research. Researchers have not addressed how

treatments may interact with the natural conditions in the classroom. They have generally failed to adequately document student responses to treatment or to adequately document the instructional process prior to and after the experimental treatment. She recommended more direct observations of students. In addition, the studies generally have not used authentic classroom materials, but rather short contrived passages for research purposes. The researchers also have not adequately considered how teachers would incorporate the experimental strategies into their instructional repertoires. She advocated the use of "naturalistic research approaches [to] complement experimental ones" (p. 231).

Future research must carefully match research questions with research design. Naturalistic research results frequently help craft more focused research questions and hypotheses, but rarely test causal relationships. A reduction in ecological validity may be necessary to more fully establish clear cause-effect relationships. This does not mean that a creative hybrid research design, in which in-depth naturalistic inquiries are nested within a traditional experimental design, is not appropriate when testing hypotheses. Such designs bring a richness to the discussions of statistical analyses and results not frequently found in comprehension research.

Regardless of the problem, the research question, or the design, science reading comprehension research must reflect theoretical frameworks grounded in both the theories of reading and science learning. Much of the research reviewed

disregarded the unique attributes of science, scientific language and text; of context; and of conceptual change. Frequently, researchers mention the natural patterns; the goal of science to search out, to describe, and to explain natural patterns; the counter-intuitive, abstract nature of science concepts; the use of specific logical text structures to record, to compare, and to relate events; the highly specific conceptual labels (vocabulary) associated with scientific knowledge networks and the resilience of students' conception in their research introduction, but they appear to neglect factoring these considerations into their research design only to suggest their inclusion in the discussion of future research.

The interactive-constructive reading model supports a conception of comprehension instruction that is strategic, that provides declarative, procedural, and conditional knowledge, and that results in self-regulated meaning-makers or knowledge architects. Comprehension instruction must consider prereading, reading, and postreading cognitive processes and the construction of understanding that integrates old and new information, abstract and concrete ideas, and theoretic and practical applications. The practice of decomposing the holistic approach into prereading, reading, or postreading strategy instruction and the tendency to explore a single strategy in isolation from other related strategies reduces much of cognitive power inherent in the interactive-constructive reading model (Pearson & Raphael, 1990). Charron (1991) outlined the importance of the social and

cultural contexts in science education research. The inherent values, beliefs, attitudes, and standards: the lived experiences: the situational characteristics and many other socio-cultural factors appear to enhance, limit, and interact with formal schooling. Future comprehension instruction research needs to more fully explore the interactions between reader-text-context and the cognitive construction of knowledge.

The definition and assessment of comprehension is a major shortcoming of current research. Immediate recall and explicit comprehension measures are the most commonly used dependent variable measures. Greater effort is required to measure knowledge constructions, meaningful learning, and implicit comprehension over a period of time. The use of think-alouds, structured interview protocols, concept maps, two-part objective questions, and performance tasks have potential application in science reading research.

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