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ABSTRACT

A study investigated how text features influence the amount of vocabulary knowledge students acquired incidentally while reading expositions. Three sets of text features were identified from studies on comprehension: (1) features associated with the macrostructure, (2) features associated with logical and temporal relations in the microstructure, and (3) features associated with explanations of concepts and relations among them. Two natural expositions were revised in three successive, incremental steps, yielding four versions for each exposition. The most difficult words in each exposition were identified. Approximately 300 eighth grade students read one text version and completed a multiple choice test written to be sensitive to small gains in word knowledge. The results indicated that both able and less able readers who read text versions in which key concepts and the relations among them had been explained thoroughly learned significantly more word meanings than did students who read any of the other versions. (Author/FL)

CENTER FOR THE STUDY OF READING

Technical Report No. 364

INCIDENTAL ACQUISITION OF WORD MEANINGS FROM EXPOSITIONS THAT SYSTEMATICALLY VARY TEXT FEATURES

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Abstract

The present study investigated how text features may influence the amount of vocabulary knowledge acquired incidentally while reading expositions. Three sets of text features were identified from studies on comprehension: (a) features associated with the macrostructure, (b) features associated with logical and temporal relations in the microstructure, and (c) features associated with explanations of concepts and relations among them. Two natural expositions were revised in three successive, incremental steps, yielding four versions for each exposition. The most difficult words in each exposition were identified. Eighth-grade students (N = 309) read one text version and completed a multiple-choice test written to be sensitive to small gains in word knowledge. Results clearly revealed that both able and less able students reading versions in which key concepts and the relations among them had been explained thoroughly learned significantly more word meanings than students reading any of the other versions.

Incidental Acquisition of Word Meaning From Expositions That Systematically Vary Text Features

Over the years, educators and theorists have hypothesized that normal reading, without special emphasis on vocabulary learning, can increase a reader's knowledge of words (e.g., Gray & Holmes, 1938; Thomas & Robinson, 1972). However, most researchers found little evidence from their studies to support the hypothesis. It has only been very recently that clear empirical evidence has emerged to support the incidental acquisition hypothesis.

Often research has failed to produce positive results because a fundamental point was overlooked: Acquisition of word knowledge generally occurs in small increments. When learners initially encounter an unfamiliar word, they may grasp only some portion of its meaning (cf. Carey, 1978; Clark, 1973). For example, while reading a passage on the development of river systems, a student who knows nothing about rills beforehand may learn that rills contain water. This partial knowledge of rills may be sufficient to respond to a multiple-choice item when none of the distractors mention water, but it would be insufficient to respond to a multiple-choice item that required discrimination among definitions of three or four kinds of waterways. On the other hand, a second student may already know that rills are waterways and, by reading the same river systems text, figures out how rills fit into a river system. This second student added to his or her existing partial knowledge about rills. Thus, both students made incidental gains in word knowledge; but if researchers are unaware of the incremental nature of vocabulary acquisition and fail to devise tests that are sensitive to partial gains in word knowledge, they may conclude erroneously that not much, if any, incidental acquisition of vocabulary knowledge has occurred.

Furthermore, students may only acquire some portion of a word's meaning because most natural texts at best reveal only some aspect of a word's meaning to an alert reader. Beck, McKeown, and McCaslin (1983), after surveying school texts, concluded that "contexts occurring in text selections do not reliably assist readers in discovering the meaning of an unknown word" (p. 180). If researchers then proceed to test only for full adult understanding, the wrong conclusion might be reached, that is, that little incidential learning took place.

Learning Word Meanings From Written Context

Most studies investigating learning word meanings from written context have asked readers to *derive* the meaning of a specified word. That is, the reader is explicitly instructed to figure out the meanings of words highlighted in some way in context. Such studies have shown that readers from 8 years of age to college age can derive word meanings from sentences (van Daalen-Kapteijns & Elshout-Mohr, 1981; McKeown, 1985; Werner &

Kaplan, 1952) and from connected text (Ames, 1966; Boettcher, 1980; Carroll & Drum, 1982, 1983; Carnine, Kameenui, & Coyle, 1984; Elivian, 1938; Gibbons, 1940; Olson, 1971; Quealy, 1969: Sternberg, Powell, & Kaye, 1982).

On the other hand, few studies have investigated incidental learning of word meanings from written context. That is, few studies have examined how much word learning occurs when students are reading selections for a normal purpose, such as to understand and remember information in a text or to enjoy a story. Earlier researchers (Gray & Holmes, 1938; Sachs, 1943) found little evidence for such incidental learning because they employed measures that were not sensitive to incremental gains in word knowledge. Furthermore, these researchers failed to realize how uninformative natural texts can be. For example, in Gray and Holmes's study, students read two excerpts about scribes taken from a history book. Neither excerpt explicitly conveyed the concept of Egyptian scribes, although Gray and Holmes believed that the second excerpt did. Students possessed little prior knowledge of scribes and, therefore, would most likely acquire some small increment in knowledge about scribes, rather than full adult meaning. However, Gray and Holmes's measures were not designed to tap minimal knowledge and they concluded that little learning had occurred.

Some evidence for incidental acquisition of vocabulary knowledge comes from a recent study by Jenkins, Stein, and

Wysocki (1984). Students of average and above average ability read paragraphs especially constructed to imply strongly the meaning of a particular word. Some students read only two paragraphs containing a target word, while others read up to ten paragraphs. Jenkins's group found that students who encountered ten repetitions of a word acquired more knowledge than students who encountered the same word only twice. Moreover, able students learned more than less able students as evidenced on several measures of vocabulary knowledge. However, students may have been alerted to the nature of the study because they read aloud target words beforehand. Thus, learning may not have been entirely incidental

Research by Nagy, Herman, and Anderson (1985a) provides convincing evidence that incidental acquisition of vocabulary knowledge occurs during normal reading of natural text. They devised measures sensitive to various levels of word knowledge, from partial knowledge to full knowledge. Interestingly, results showed that learning occurred at all levels of knowledge. Some of the students, who were all able eighth-grade readers, went from no knowledge to some knowledge, while others went from some knowledge to fuller knowledge of the words, even though most words appeared only once in the narrative or exposition.

Because Nagy, Herman, and Anderson's first study (1985a) involved only one grade level, one narrative, and one exposition, they conducted a second study (1985b) that spanned three grade levels, employed 12 texts, and recruited students from a range of ability levels. Gains in vocabulary knowledge were assessed one week after reading. Results showed that a significant amount of vocabulary knowledge was acquired incidentally while reading, regardless of student ability.

What is unsettling about Nagy, Herman, and Anderson's results is that in their first study the amount of learning from the exposition was about the same as for the narrative; but in their second study, the amount of learning from expositions was actually less than from narratives. These results are puzzling because expositions generally are written to convey the meanings of key terms. Thus, it seems reasonable to expect students to gain more word knowledge from expositions than from narrative; however, in Nagy, Herman, and Anderson's studies, they did not.

Schema theory provides some insight about why students in Nagy, Herman, and Anderson's studies may have acquired fewer new words while reading expositions than while reading narratives. A schema is an organized network of concepts embodying some aspect of knowledge. Experts have complete schemas related to their area of expertise. Nonexperts, on the other hand, may have only bits and pieces of a schema. If experts on circulation, for instance, read a poorly written text on the topic, they are able to piece the message together by filling in missing information about concepts and their relations. Most students, however, are nonexperts and do not possess enough information to reason about missing pieces of information (cf. Bransford, 1984).

The expositions used in the studies by Nagy and his colleagues may have presented concepts and their relations in a rather arbitrary, list-like fashion; and nonexpert students may not have possessed the schemata necessary to make sense out of the text. Perhaps if the expositions had been written to convey information more completely and precisely, students would have acquired more vocabulary knowledge incidentally. However, no research exists exploring how the quality of a text and acquisition of word knowledge are related. Some text features may positively enhance vocabulary acquisition in expositions while others may not. Without empirically based guidelines for constructing an exposition, writers and editors may create expositions that are ineffective in promoting learning.

Influences of Text Features on Learning

Some level of text comprehension is prerequisite to incidental vocabulary acquisition. Hence text features that influence comprehension also influence word learning. Text features that have been shown to influence comprehension include aspects of the macrostructure (i.e., aspects of global coherence, such as the quality of titles, topic sentences, and organization), features associated with the microstructure (i.e., logical and temporal relations expressed in text), and the completeness of explanations of concepts and relations among them.

Influences: Macrostructure

Macrostructure is expressed in text through titles, topic sentences, and by the overall organization and flow of information. Knowledgeable readers may use such information to gain an initial understanding of information in a text.

Several studies have investigated the effect of titles on understanding of a passage. In a number of studies designed to evaluate the effect of schemata on comprehension (Bransford & Johnson, 1972; Dooling & Mullet, 1973; Schwartz & Flammer, 1981), hopelessly vague and ambiguous passages were comprehended better by readers who were given a title prior to reading. However, when more natural texts have been used, texts containing recognizable contextual clues about passage themes, titles and headings have not proven effective (Hartley, Trueman, & Pigram, 1984; Nist & Hogrebe, 1984; Watanabe, Hare, & Lomax, 1984). Unambiguous passages may be sufficiently redundant to eliminate the need for explicit titles.

How helpful topic sentences are in aiding readers' understanding of a text is unclear. Aulls (1975) found that students recalled more about a poorly structured paragraph on an unfamiliar topic when that paragraph had a title and an initial topic sentence. However, Hidi (1984), who employed natural passages from social studies texts, concluded that the addition of topic sentences did not affect performance on comprehension measures. Other researchers investigating where topic sentences should occur to maximize a reader's chance for grasping ideas have found that readers encountering unfamiliar text may read more accurately when there is an initial topic sentence (Kieras, 1980, 1981); apparently such a sentence provides them with immediate, more accurate access to top-level information in the text. Other researchers have found that topic sentences appearing in the middle of paragraphs were remembered just as well as those appearing at the beginning (Kintsch, Kozminsky, Streby, McKoon, & Keenen, 1975; Meyer, 1977).

Awareness of the macrostructure of a text leads the reader to expect information relevant to that framework. What happens to understanding if a passage contains some irrelevant sentences or inadequately explained information? Such "inconsiderateness" (Anderson & Armbruster, 1984) should have differential effects on readers (Kucer, 1983), depending upon prior knowledge, reading ability, interest, attitude, problem solving ability, and so on.

Just how much of a roadblock inconsiderate text is to comprehension is not well understood, though research has yielded some preliminary answers. Freebody and Anderson (1983) inserted two extraneous propositions in each of several passages. The effect of these propositions on comprehension measures was not clear-cut; but Freebody and Anderson concluded that "inconsiderateness tended to suppress performance" (p. 285). Hayes-Roth and Thorndyke (1979) found that formation of an integrated memory representation for two related facts is less likely if common information is paraphrased and intervening material occurs between the presentation of the two facts.

Influence: Microstructure

Aspects of microstructure that influence comprehension are the logical and temporal relations that hold between propositions in text. Such relations or ties between adjacent sentences are expressed in text, for instance, through reference ties (nouns co-referring to pronouns), substitution ties (nouns co-referring to words such as one), or conjunctive ties (e.g., first or but). Signaling (Meyer, 1977) is similar to conjunctive ties; that is, words and phrases (e.g., "an important point is") that do not add new content but are used to identify significant information or express how information in text is related.

Relations expressed in text can be either implicit or explicit, depending upon the presence or absence of ties in the surface structure. To understand an implicit relation, a reader must infer a meaningful connection between two or more pieces of information in text. This takes time and may not be done, or may be done incorrectly. On the other hand, when the relational connective is explicitly expressed in text, a reader may process information more quickly and accurately.

Evidence from studies involving only logical and temporal relations within and between sentences shows that when surface relations in sentences are made explicit, a reader's understanding of the sentences increases (Bormuth, Manning, Carr,

& Pearson, 1970; Hayes-Roth & Thorndyke, 1979; Kameenui & Carnine, 1982; Richek, 1976). Less able readers understand sentences better when logical and temporal relations are explicitly stated (Irwin, 1980; Marshall & Glock, 1978).

When longer texts are involved, the effect of implicit and explicit relations on understanding is not as clear. Most studies using longer text involved only able readers and found little difference in performance on comprehension measures between students reading texts that had more explicit relations and students reading texts that had more implicit relations (Freebody & Anderson, 1983; Hagerup-Neilsen, 1977; Neilsen, 1981; Roen, 1984). Studies that have included less able students provide mixed evidence. Tenth-grade poor readers in a study by Loman and Mayer (1983) integrated information so well in a conceptually considerate exposition to which signals words had been added that they were able to apply their new knowledge to solve a novel problem. Students reading the unsignaled version knew bits and pieces of information but were unable to integrate them in order to solve the problem. Younger poor readers in another study (Meyer, Brandt, & Bluth, 1980) did not recall more information after reading a text with signals; however, "difference" poor readers did (i.e., readers with adequate word knowledge and decoding skill but poor comprehension; see Wiener & Cromer, 1980).

Influences: Conceptual Elaborations

The major thesis upon which the present study is based is that something beyond surface manipulations is needed to alter learning. Even though a text may have relations explicitly expressed on its pages, readers, particularly some less able readers or able readers attempting to understand text about an unfamiliar domain, may miss essential understandings because concepts and relations among them are not sufficiently explained.

The idea that supplying learners with explicit explanations of relationships among concepts in expositions will be helpful comes from schema theory. Schemas are structures in the sense that component parts are meaningfully related (see Anderson, 1984, or Anderson & Pearson, 1984). When students possess little knowledge about the topic of a text, they may not understand some or all of a text because they do not understand how the network of concepts fits together (e.g., Chiesi, Spilich, & Voss, 1979; Steffensen, Joag-Dev, & Anderson, 1979). However, when such students read text in which concepts and their relations are explicitly and precisely expressed, comprehension improves (Bransford, Stein, & Vye, 1982; Franks, Vye, Auble, Mezynski, Perfetto, Bransford, Stein, & Littlefield, 1982; Moes, Foertsch, Stewart, Dunning, Rogers, Seda-Santana, Benjamin, & Pearson, 1984; Peters, 1975; Stein & Bransford, 1979).

Evidence for the foregoing analysis comes from two studies by Bransford and his colleagues using passages about robots. In the first study (Bransford, Stein, & Vye, 1982), able and less able fifth-grade students read a passage about two kinds of window-washing robots. One version described the parts of each robot in list fashion, leaving implicit the function of each part; the other explained the significance of robot parts to their window-washing function. When asked to recall the parts of each robot and tell why a robot had a particular part, able students reading either the explicit or implicit version performed equally well. Able students reading the implicit version could correctly infer form and function relations; however, the less able readers were quite poor at recalling parts of the robot and explaining the significance of the part. Only when these students read the explicit version was performance improved. Similar results occurred in a later study that also employed robot passages (Franks et al., 1982).

Besides precisely specifying form and function relations in text, other types of relations (e.g., part-whole) could be elaborated, as well as providing key information about the features of concepts. Tennyson and Park (1980) and Frayer, Frederick, and Klausmeier (1969) have spelled out steps that can be taken to elaborate a concept: Informing readers specifically about member-set relations of a concept and giving details relevant to the concept.

Two studies using Frayer, Frederick, and Klausmeier's (1969) ideas have examined the value of expressing information in text more precisely. Peters (1975) hypothesized that if target concepts in a social studies text were explained in this manner, good and poor ninth-grade students' understanding of the concepts would improve greatly; and this was the case. In another study, Moes et al. (1984) found that science passages written using these ideas significantly improved able seventh-grade readers' comprehension. However, Peters and Moes and her associates did not investigate whether one or more aspects of these guidelines were more effective than others.

From the literature reviewed, it appears that text features found in an informative macrostructure and in precise conceptual elaborations stand as the most likely candidates to boost understanding, and thus possibly to boost acquisition of vocabulary knowledge. The least likely candidate is adding explicit markers for implicit logical and temporal relations already in the text. Therefore, unless a passage already contains a sufficiently elaborated treatment of concepts for the intended audience, the presence of more connectives is unlikely to increase understanding and vocabulary acquisition significantly.

The purpose of the present study is to investigate how expositions that systematically vary in the quality of text features (i.e., features expressed in the macrostructure, in logical and temporal relations already in text, and in conceptual explicitness) affect a reader's incidental acquisition of vocabulary knowledge. Specifically, the study addresses these questions:

1. Do middle-grade students who have read an exposition know more word meanings than students who have not read the text?

2. Does student ability influence incidental acquisition of word knowledge?

3. Of the three categories of text features one might use to revise a text--macrostructure, microstructure, or conceptual elaborations--which has the greatest effect on incidental word learning?

Method

Subjects

A total of 413 eighth-grade students in three junior high schools located in a mid-sized midwestern town participated in the study; however, 63 were dropped because they missed the pretest, 20 were absent the day the text was read, 11 were absent the second day of posttesting, 5 did not finish the vocabulary posttest, 1 was dropped because of extremely low reading ability, and 4 were dropped because the text version they read was not recorded. Only students for whom complete data were available (*N* = 309) were included in the analyses.

Materials

Two texts, each about 1000 words long, were chosen from junior high science books: one about river systems (Bishop, Sutherland, & Lewis, 1981) and one about the circulation of blood in humans (Heimler & Lockard, 1977).

Three versions of each text were created by editing the previous version according to one of the three categories (macrostructure, microstructure, concept elaborations) of text features. Each revision increased the explicitness with which the text conveyed its message to the reader (see Table 1 for guidelines used). The versions were (a) the Original text, (b) the Macrostructure version which was the Original text with revisions made in the macrostructure, (c) the Microstructure version which incorporated all changes made in the Macrostructure version, plus additional revisions to make key textually implicit information explicit, and (d) the Elaborated version which included all previous changes, plus revisions that elaborated key concepts and their relations. Texts were reproduced without illustrations on plain white paper.

Insert Table 1 about here.

Original version. The first version of each text was a verbatim reproduction of the original text. Most typographical features, such as boldfacing, were retained.

Macrostructure version. In the Macrostructure version, revisions were made in the titles, topic sentences, and organization. Most of the original titles consisted of one or two words, and none of them explicitly alerted the reader to the rhetorical intent (e.g., explanation) of the upcoming section. Titles were altered to convey explicitly the topic and intent of each section.

Revisions were made to improve the arrangement of text content and to eliminate irrelevant and inappropriate content in the Original text. Deleting irrelevant portions of text and moving sentences and paragraphs to sections where they were relevant improved the organization of information.

Most information was topically grouped in the river systems and circulation texts. Both texts, however, had some information that was not. In the Original circulation text, for example, sentences about the heart pumping blood appeared in several sections. All of this information was moved into one appropriate section.

Another consideration in deleting information was audience appropriateness. Information could be relevant, but not appropriate for eighth-grade students either because these students lacked the prior knowledge to understand it, or because the text inadequately developed the concepts. In the Original river systems text, for instance, a paragraph on "profile of equilibrium" was judged inappropriate for the audience by several adult reviewers (all of whom had teaching experience) and, therefore, was deleted.

Finally, topic sentences were written for paragraphs without them. For example, in the Original river systems text, a paragraph described several land formations built up from sediment. However, the paragraph had no topic sentence. An initial topic sentence was added to signal that the paragraph was going to describe three places where land forms were likely to develop.

Microstructure version. All Macrostructure revisions were carried over to the Microstructure version. In the Microstructure version, information was inserted to make explicit relations that were only implicit in the Macrostructure version. Explicitness was achieved by adding phrases, clauses, or sentences to make comparative, contrastive, sequential, and conditional relations explicit; by adding conjunctions, adjectives, or adverbs to signal such relations; and by replacing unclear anaphora with unambiguous words.

Elaborated version. All changes made in earlier versions were carried over to the Elaborated version. The aim of the Elaborated version was to add information to the text about key concepts and their relations by thoroughly explaining important concepts, by specifying relations among concepts, and by adding informative examples. Incorporating all of these ideas added quite a bit of information to the Elaborated text: The original version of the river systems text was 1230 words long; Elaborated version was 1973 words.

Important ideas and their relations were determined by what the researcher, an experienced middle-grade teacher, perceived to be important in light of the total message, by her own knowledge of the domain, and by her feel for the intended audience, eighth-grade students.

Table 2 gives examples of the treatment of floodplains and levees in the four versions. In the Macrostructure version, a topic sentence was added and two sentences appearing in the Original text were deleted. The deleted sentences contained concepts (e.g., "meander belt") that were never explained anywhere in the chapter and were judged not to be key to understanding the overall message. In the Microstructure version, signal words were added to alert the reader to where fine and coarse sediments were deposited. Neither of these versions explained how and where each type of sediment is deposited, nor do they provide a reason for deposition in various places. The Elaborated version provides such linking information.

Insert Table 2 about here.

A traditional readability analysis (Fry, 1977) was performed on the Original text and on the Elaborated text. The grade level readability for the Original circulation text was about 7.5; interestingly, this text was unusual because it had very short sentences and lots of multisyllabic words, a rare combination in texts. The reading level of the rewritten Elaborated text was about 7.4. For the Original river systems text, on the other hand, the grade level was about 10.2, while the Elaborated text was about 8.8. Thus, in this case, the rewritten text appears to be closer to the level of the intended audience. It should be noted that there was no direct attempt to reduce readability while creating each version; instead, the reduction in readability level, as measured by the Fry analysis, resulted coincidentally from the process of applying all the revision guidelines.

Target Words

Target words were identified using two measures of difficulty. First, 5 adults with teaching experience circled the most difficult words in the Original texts. All words identified as difficult by the 5 raters became target words. Second, other low frequency words were identified using the Standard Frequency Index (SFI) from Carroll, Davies, and Richman (1971). Any words in the text that had an SFI of 40 or below became target words also. A total of 46 target words was chosen (see Table 3).

Insert Table 3 about here.

The use of real words from actual texts increases ecological validity, but it makes it difficult to assure that students did not already know the meanings. However, both the scores on the checklist test, administered before the main study, and the performance of the students on target words not in the text they read served as statistical controls for assessing the likelihood of a word having been known before the experiment.

Measures

Vocabulary pretest. The Anderson-Freebody Checklist Vocabulary Test (Anderson & Freebody, 1983), which yields data on each subject's self-reported prior knowledge of the target words, served as the pretest measure of word knowledge. The posttest vocabulary measure was a multiple-choice test.

The checklist test was chosen primarily because it gives the subject no information about the meanings of the words tested. It also is sensitive to partial word knowledge; subjects tend to mark a word as known even if they have only a partial grasp of its meaning (Anderson & Freebody, 1983). A weakness of the checklist test is that it is not suitable for use as a posttest.

The checklist test consisted of 191 items in the following categories: (a) target words: 24 river systems words, 22 circulation words; (b) general vocabulary: 50 words from Dupuy (1974) representing a range of word difficulty (see Nagy, Herman, & Anderson, 1985b), plus five non-target river system words and six non-target circulation words; (c) decoding distractors: 28 items which would be marked as known only if a student made a decoding error (e.g., weast); (d) pseudo-derivatives: 28 items which are not exisiting English words but which are constructed from existing English stems and affixes (e.g., <u>bloodible</u>); (e) nonwords: 25 items which are not English words but follow English spelling pattern conventions (e.g., <u>felinder</u>). Only these nonwords were used in computing the correction factor for a student. Three versions of the checklist test were constructed, each with different ordering of items.

<u>Vocabulary posttest</u>. For the vocabulary posttest, a multiple-choice test was constructed by the author following the procedures of Nagy, Herman, and Anderson (1985b). Each of the 46 target words appeared twice in the test at two levels of difficulty. Level of difficulty was manipulated by controlling the kind of distractors used in the items. All distractors were short definitions for real words. At the easiest level, distractors were phrased for a different part of speech than that of the target word. Furthermore, distractors at the easier level were more semantically distant from the target word, but still part of the knowledge domain. In contrast, at the more difficult level, distractors were phrased to be the same part of speech as the target word, and to be semantically close to the target word (see Table 4).

Insert Table 4 about here.

Each item in the test had the correct answer, three distractors and a "don't know" option. The correct answe appeared an equal number of times in the first four positions. "Don't know" was always in the last position. Correct answers to a given item appeared as distractors in other vocabulary items at least twice so that students would be unlikely to associate a specific phrase as appearing only with a specific stem.

To assemble student test booklets, each of the 92 multiple-choice items was selected and placed in one of four blocks. Only one item per word appeared in any one block. Easier and harder items were placed in nonadjacent blocks. Blocks were balanced by topic and by level of item difficulty. Items within blocks were not randomized, but the order of blocks was counterbalanced by following the logic of a Latin Square to create four test versions. Thus, if the order of completing the blocks had some effect on performance, the effect would be balanced to some extent.

Essay posttest. As an alternate way to assess effects of text revisions, two short essay tests were created, one for each domain. The essay format was chosen over a multiple-choice format so that students could write about concepts and their relations. It must be acknowledged that for some students, composition, spelling, and even penmanship were obstacles to explaining all they knew.

Procedures

Pretest. Two weeks before the main study, the checklist test was administered during regular school hours. The examiner randomly distributed three versions of the checklist test and read the directions aloud. Students worked at their own pace. Students had 15 minutes to complete the test.

Main study: First day. Text versions were arranged so that each of the eight versions would be equally represented within classrooms when the tests were randomly distributed. Adjacent students were given versions about different domains. A researcher read the direction page aloud. Students were told they would have 10-15 minutes to read the text and that they would answer questions about the text afterwards without seeing it. Vocabulary was not mentioned. Students finishing early either sat quietly or reread the text.

When all students finished reading, they turned over their text and began a 5-minute filler task. This brief task was included to direct student's attention away from the text content and prevent them from actively rehearsing what they had read. Thus, students were less likely to answer from short-term memory while working on the posttest.

Multiple-choice booklets were passed out randomly. Adjacent students did not receive the same version. The last two blocks of test items were sealed shut so students would not be able to look at it while they completed the first two blocks. The examiner then read the directions and sample items. While students worked on the test, the examiner collected the face-down texts. Students had 20 minutes to complete the first half of the test.

Main study: Second day. The multiple-choice booklets were returned to the students. After the researcher briefly reviewed the directions, students broke the seal and completed the second half of the test. Students were instructed not to turn back to completed pages. No student was observed doing so. Up to 20 minutes was allotted for the test. As students finished the multiple-choice test, one of the examiners collected it, gave the student the appropriate essay questions, and briefly explained directions.

Scoring

Checklist test. The checklist test was scored +1 for a hit and 0 for a miss. Items skipped by students were omitted from the analyses.

From the checklist data, a general vocabulary score (using only Dupuy's words) was calculated and adjusted for guessing by subtracting the proportion of false alarms (FA) on nonwords from the proportion of hits (PH) on general vocabulary words, then dividing the difference by one minus the proportion of false alarms: (PH - FA)/(1 - FA), the standard high-threshold correction for guessing. This score was used to estimate (via the linear regression equation) comprehension percentiles for 8 students who were missing the standardized score from the Comprehensive Test of Basic Skills (CTBS).

Multiple-choice posttest. For the multiple-choice data, correct answers received +1. The multiple-choice data were adjusted for guessing by applying a correction and assigning a value of -.33 to incorrect answers on the grounds that for every correct guess, the student would make three wrong guesses. "Don't know" received zero. Questions skipped by students were omitted from the analysis.

Essay tests. To establish a template for scoring the essays, the researcher and another educated adult, using the Elaborated version, wrote the best answer the could to each essay question. Then they compared their answers and resolved disagreements by checking the text and by discussing what a basic answer should contain. Basic answers dealt only with essential content.

A scoring grid was created from each master answer by writing it in a list format. This grid represents a simplified version of Turner and Greene's (1977) text analysis procedure.

Two researchers, who were unaware of which version a student had read, independently scored a randomly selected subset of the essays in order to establish interrater reliability. The reliability was 0.91 (number of agreements divided by the total number of items).

Design and Analysis

A mixed factorial design was employed. Between-subject factors were Text Student Read (river systems or circulation); Text Version (Original, Macrostructure, Microstructure, or Elaborated); and Ability (comprehension percentile on the CTBS).

Within-subject factors were Prior Knowledge (the subject's self-reported prior knowledge of all target words on the checklist test); Word Source (text, circulation or river systems, in which target words appeared); Block Order (position in the test), Day (the first or second day of posttesting), and Question Difficulty (easier or harder). The dependent measure was a 92-item multiple-choice test.

Hierarchical multiple regression analyses were performed on the multiple-choice data following the logic of analysis of variance. The total variance was partitioned in the following order: (a) Grand Mean (a subject's mean performance on all target words on the multiple-choice test), (b) within-subject factors, (c) interactions of within-subject factors, (d) between-subject factors, (e) interactions of within-subject and between-subject factors (see also Anderson, Mason, & Shirey, 1984). The between-subject factors were not of intrinsic interest as main effects and were not evaluated; they were included solely to permit an analysis of interactions that were of interest. Each set of interactions was coded for step-wise inclusion (i.e., allowed to compete for explained variance) because little was known about which ones were likely to be significant. Factors, when they were nonsignificant and were not part of a significant interaction, were eliminated from the regression. Nonsignificant interactions were eliminated also. The comparison-wise alpha level was set a priori at .01 to minimize experiment-wise error.

Text Versions were coded a priori for three orthogonal contrasts. Text Version contrasts compared performance as follows: (a) the Elaborated version against all other versions, (b) the Macrostructure and Microstructure versions against the Original text, and (c) the Macrostructure version against the Microstructure version.

Block Order was coded a priori for three orthogonal contrasts. The first contrast compared performance on the first block completed on each posttesting day with performance on the second block. The second and third contrast compared performance within days.

In the regression analysis, the F ratio for each step was recalculated off-line by dividing the increment in R^2 unique to the step (this is the squared semi-partial correlation or ΔR^2) by the quantity resulting from one minus R^2 taken from the final step in the analysis, divided by the total number of subjects minus the total number of steps in the full model minus one: $R^2/(1 - R^2)/(N - K - 1)$.

Initially, two regression analyses were performed to determine if groups receiving the different versions of the texts varied in ability and prior knowledge of the words. The predictor variables in both analyses were the Text Version contrasts described earlier. In the first analysis, the dependent measure was the comprehension scores expressed as percentiles on the CTBS. In the second analysis, the dependent measure was the scores from the checklist test. In each analysis, the increment in $\underline{R}^2$ unique to each contrast was pooled and divided by 3. This quantity was then divided by the appropriate error term: the residual variance ($1 - \underline{R}^2$ in the final step) divided by the appropriate degrees of freedom (the total number of subjects minus the number of steps, minus one): $(\Delta\underline{R}^2/3)/(1 - \underline{R}^2)/(\underline{N} - \underline{K} - 1)$.

Hierarchical regression analyses were performed analyzing the multiple-choice data, wherein the unit of analysis was each subject's performance on each and every test question. All interactions that were of logical interest were explored and nonsignificant interactions were dropped from the model in the manner described earlier.

Finally, an analysis of the residual variance was done to determine any possible violations of underlying assumptions for linear regression analysis. No violations were found in the scatterplot involving figures from the analysis in which the final reduced model was fit to the data ($\underline{r} = 0$, between residuals and predicted values of the dependent measure).

Essay data were analyzed in a between-subjects regression procedure that followed the logic of an analysis of covariance. The covariates were Ability and the Prior Knowledge score from the checklist test. Text versions were coded a priori in three orthogonal contrasts as described earlier. The unit of analysis was an individual subject's performance on the essay.

Analysis of covariance was accomplished through a hierarchical regression procedure. Separate regression analyses were performed on the river and circulation data; then an analysis of the combined data was performed. Nonsignificant covariates, Text Version contrasts, and interactions were deleted from each model.

Results and Discussion

Group Equivalency

Results from regression analyses assessing the equivalence of groups reading the four text versions indicate that the groups were not significantly different in ability, F (3,307) = 1.67, $p > .01$. However, the groups were significantly different in prior word knowledge, F (3,28630) = 9.86, $p < .01$. Students reading the Elaborated version checked significantly more words as known than students in the other groups.

Group differences were controlled for statistically. First, each student's Grand Mean, which was a student's mean performance on *all* words on the multiple-choice test (i.e., words from the text the student read and from the text not read), entered into the regression analyses. Grand Mean accounted for variance associated with all possible differences between students. Second, each student's Prior Knowledge score from the checklist test was entered as the second step in the regression analyses to account for variance associated with particular patterns of knowing and not knowing the target words.

Vocabulary

The overall results from the regression analyses performed upon the multiple-choice test appear in Table 5. In the final regression model, variables and their interactions entered in the order shown in Table 5. The percent variance refers to the increment in $\underline{R}^2$ unique to that step. Each regression coefficient indicates the increase or decrease in the dependent measure associated with one unit change in the variable listed in the first column. Note that the coding of variables is explained under the table. Results are organized and discussed around the key questions posed earlier. Other findings are presented afterwards.

Insert Table 5 about here.

Learning from context. The first question is, do middle-grade students who have read an exposition know more word meanings than students who have not read the text? Evidence from the present study indicates an affirmative answer and replicates the results found by Nagy, Herman, and Anderson (1985a, 1985b).

Acquisition of word knowledge, or Learning from Context, is the interaction of Text Student Read and Word Source (see Table 6). For example, on the multiple-choice test, students who read the river text scored a mean of 54% correct on questions taken from that text for the posttest. However, students who read the circulation text answered correctly only 43% of the questions taken from the river systems text. Therefore, students who read the river systems text answered correctly about 11% more of the questions from the river text than students who had not read that text. While appearing to be small in absolute terms, this gain is statistically robust.

Insert Table 6 about here.

Degree of learning was not influenced significantly by Question Difficulty, Day, Prior Knowledge, or Block Order. However, it was influenced by Ability and Text Version read. Each of these statistically significant interactions will be discussed in turn.

Ability and learning from context. The second question the present study addresses is, does student ability influence incidental acquisition of word knowledge? Evidence in Table 5 and Figure 1 shows the significant contribution of ability in learning from context.

Figure 1 illustrates the statistically significant interaction of Learning from Context and Ability. At the 3rd percentile, about a 7% difference exists in learning between students in the Read condition and students in the Not Read condition. (Read refers to a student's posttest performance on words that were from the text the student actually read; Not

Read, to performance of the same students on words taken from the text that was not read.) By the 50th percentile, students in the Read condition were 12% higher; at the 99th, about 17% higher. Overall, able students learned word meanings more than less able students.

Insert Figure 1 about here.

The significant interaction of Learning from Context and Ability does not appear to be a statistical artifact. The mean percentile for ability, 59.5 (SD = 24.4, range: 3rd percentile to 99th percentile), gives no indication that there was a floor or ceiling effect. An analysis of the residual variance revealed no outliers that could have influenced the analysis substantially or any curvilinear trends. The Ability and Learning from Context interaction was not conditioned by Prior Knowledge, Text Version, Block, Day, or Question Difficulty. Therefore, the interaction appears to be genuine and linear.

Another way to portray the role of ability is to calculate the probability of learning an unknown word at the easier or harder level of difficulty for students at different levels of ability (see Table 7). The probability of learning a word at the given level equals the increase in number of words known at that level, divided by the number of words originally not known to that level: (Read - Not Read)/(1 - Not Read). The least able readers had a probability of 0.05 to 0.10 of learning an unknown word from context. The most able readers, on the other hand, had a 0.26 to 0.46 probability of learning of learning an unknown word from context. Thus, the two groups have a clearly different potential for acquiring word knowledge incidentally while reading.

Insert Table 7 about here.

The significant interaction of learning and ability found in the present study finds some support from Jenkins, Stein, and Wysocki's (1984) study, but no support from Nagy, Herman, and Anderson's (1985b). Both of these studies investigated incidental learning of word meaning from context, and both studies included students varying in reading ability. Nagy and his colleagues chose natural narratives and expositions, one easier and one more difficult, for each of the three grade levels included in their study. Given the span of ability within and between grades, Nagy and his associates expected learning and ability to interact; but no hint of an interaction was found.

On the other hand, Jenkins, Stein, and Wysocki (1984) did obtain a significant learning by ability interaction. Able readers acquired significantly more word meanings than less able readers when comparisons were made between words that had appeared in contexts and words that had not (analogous to Read and Not Read conditions in the present study). Jenkins and his colleagues postulated that able readers may be more "word conscious," or may be better at deriving word meanings from context. Results from the present study lend some support to this claim.

Studies investigating able and less able reader's ability to *derive* word meanings from context have shown that able students can figure out more word meanings than less able students can (e.g., Carroll & Drum, 1[illegible]; McKeown, 1985; Shefelbine, 1983). Thus, able readers gain more word knowledge than less able readers when attention is focused only incidentally on word meaning, and when attention is focused purposefully on deriving word meaning.

Text version and learning from context. Does the text version a student reads influence incidental acquisition of vocabulary knowledge? The interaction of Text Version with Learning from Context is displayed in Table 8. The effect of Text Version was evaluated in three orthogonal contrasts. Of the three contrasts, only the one comparing the Elaborated version with the other versions interacted significantly with Learning from Context (see Table 5). The positive *b* weight for this interaction when it entered into the analysis (and in all steps thereafter) indicates that the Elaborated version led to more vocabulary learning than did any of the other versions. This increased learning was not conditioned by Question Difficulty, Day, Block, Ability, or Prior Knowledge. Able and less able students alike benefited from reading the most considerate version.

Insert Table 8 about here.

That students reading the Elaborated version gained more word knowledge than students reading any of the other versions was not unexpected. Previous research has yielded mixed results on the effectiveness of macrostructure revisions in improving comprehension. Titles have been shown to be most effective when passages were completely ambiguous (e.g., Dooling & Mullet, 1973) or on a less familiar topic (Aulls, 1975); otherwise, their presence has made little difference (e.g., Watanabe, Hare, & Lomax, 1984). Topic sentences combined with titles have positively altered some students recall of paragraphs on a less familiar topic (Aulls, 1975); but topic sentences simply added to a passage (e.g., Nist & Hogrebe, 1984) or in conjunction with better organization of the passage (Hidi, 1984) have not increased understanding significantly. Although regrouping topical information in disorganized passages might be expected to improve learning (Anderson & Armbruster, 1984), the evidence is mixed, with few studies yielding positive results (e.g., Schwartz & Flammer, 1981) and several negative results (e.g., Freebody & Anderson, 1983; Hayes-Roth & Thorndyke, 1979).

How does the Original text compare to texts used in previous studies? The Original text contained some paragraphs on less familiar topics, some paragraphs without topic sentences, and some information that was not topically organized. However, most of the information was thematically grouped, most of the paragraphs had topic sentences, and most sections had at least a brief title. Thus, in balance, the Original text may have had a sufficiently considerate macrostructure to permit as much incidental learning as was found when the macrostrucutre was improved.

Based on results from previous research (e.g., Freebody & Anderson, 1983; Meyer, 1975; Neilsen, 1981), microstructure revisions made in logical and temporal relations already present in text were not expected to affect learning from context significantly, even though the Original text contained many such relations that were not explicitly cued. However, there was the possibility that when combined with a considerate macrostructure, students would gain significantly more word knowledge than those reading only the Original text. No hint of such an effect occurred.

The fact that learning, ability, and text version did not interact is surprising, given the results of Bransford and his colleagues on "precise" elaborations (Franks et al., 1982). They found that when less able readers were provided with the exact information needed to make relations in text less arbitrary, they greatly improved their recall of a paragraph. In the present study, less able students reading the Elaborated version gained more word knowledge than less able students reading other versions, but the more explicit version did not help them to any greater degree than it helped more able students. The Elaborated texts in the present study were much longer than Bransford's (Bransford's: 72 words; Elaborated version, 1973 words) and contained a much heavier conceptual load than Bransford's. The fact that the less able readers benefited at all from reading the Elaborated version is noteworthy.

How reading each of the versions affected the probability of a student's learning an unknown word at the easier or harder level of question difficulty appears in Table 9. At both levels, the highest probability is for students who read the Elaborated version. The probabilities calculated at the harder level, which depended more heavily upon a student's understanding of how word meanings fit into a network of concepts, reveal the effectiveness of the Elaborated text in boosting learning. For the Elaborated text, the probability of learning an unknown word is twice as much as for the Original text, quite a substantial difference.

Insert Table 9 about here.

The probabilities of learning an unknown word from reading only the Original text can be compared to probabilities calculated by Nagy, Herman, and Anderson (1985a) because both studies employed eighth-grade students, natural expositions, and multiple-choice questions written at easier and harder levels. The studies differed, however, in that Nagy, Herman, and Anderson had only able readers, two natural texts, and only assessed word learning immediately after reading; while the present study had readers ranging from the 3rd to the 99th percentile, employed two expositions, and assessed word learning immediately after reading and 24 hours later. Remarkably similar probabilities occurred at the easier level: Nagy et al., 0.21; present study, 0.23. However, probabilities at the harder level are not as similar, but still are in the same general range: Nagy's study, 0.15; present study, 0.10. Thus, students in both studies had about one chance in five of acquiring enough knowledge about an unknown word from context to answer the easier questions, and between one chance in seven and one chance in ten of learning enough to answer the harder questions correctly.

Other Results

Block order and day. Two factors related to test order were statistically significant: Block Order and Day. Students scored higher on the first blocks completed each day. Apparently, by the second block, students became fatigued and answered the questions with less care. In addition, students performed significantly better the second day of posttesting. Perhaps students learned something about the words from taking the test the first day and performed better on the second day.

Prior knowledge. Prior Knowledge, (i.e., student's checklist test performance on words from the text read) was highly significant. The positive b weight indicates that posttest performance was better on words that students had checked as known on the pretest. How Prior Knowledge was influenced by Question Difficulty is discussed in the next section.

Question difficulty. Question Difficulty was statistically significant (see Table 5). The positive b weight when Question Difficulty entered into the analysis shows that easier questions resulted in higher scores. Question Difficulty was conditioned by Prior Knowledge and Word Source. Figure 2 displays the interaction with Prior Knowledge. Significantly more words that were checked as known on the pretest were answered correctly on the posttest at the easier than at the harder level.

Figure 3 shows the significant interaction of Question Difficulty and Word Source. A significant difference in performance on the posttest occurred at the easier level when Word Source was taken into account. Significantly more easier questions were answered correctly if words were from the circulation text. This difference, however, reverses at the arder level where students answered correctly more questions if words were from the river systems text.

Insert Figures 2 and 3 about here.

Word source and ability. The significant interaction of Word Source and Ability is displayed in Figure 4. As can be seen in Figure 4, less able readers at the 3rd percentile answered about 10% more items correctly that were based on the circulation text than those based on river systems, regardless of whether or not students had read the text. However, by the 99th percentile, this difference almost disappears. Thus, more questions were answered correctly from the circulation text by less able students; questions from the two texts were equally difficult for the most able students.

Insert Figure 4 about here.

Word source and text version. As indicated by the means in Table 8 and by the negative b weight in Table 5, more questions were answered correctly by students reading the Elaborated version when the questions were from the circulation text.

Insert Table 10 about here.

Essays

The students reading the Elaborated version were expected to score the highest on the essays; however, text versions apparently made little significant impact on learning and remembering as measured by written responses to general questions.

Two factors may have contributed to the results of the essay test. First, the essay analyses had considerably less statistical power. Second, the questions may have prompted scanty answers. Most students took the quickest route to finishing and wrote *very* short answers, answers that were generally less than a sentence.

Assessing changes in knowledge through analyzing free recalls, however, has not always been a sensitive measure of learning. Research conducted by Loman and Mayer (1983) showed little difference in the total amount of propositions recalled by students reading either a text with explicit microstructure or the text without explicit microstructure. Differences in understanding showed only when students were asked to apply knowledge gained from reading to solve a novel problem. Thus, more sensitive measures might have captured changes in understanding.

Conclusions

The major finding of the present study was that students reading the conceptually elaborated version gained more word knowledge than students reading the original texts or any of the other revised texts. The Elaborated version provided a more thorough description of important concepts, explained clearly relations among them, particularly relations between form and function, and gave typical examples of concepts that were unlikely to be known by the students. Other revisions did not contain such complete information. For example (see Table 11), the Original circulation text tells where blood flows during portal circulation, but never explains why it is important for blood to flow through the small intestines and liver. The Elaborated version, on the other hand, thoroughly describes why.

Insert Table 11 about here.

Complete explanations of key concepts appear to be critical to nonexpert middle-grade students in their acquiring vocabulary knowledge incidentally from expositions. Less able readers as well as able readers gained more vocabulary knowledge from reading the Elaborated text, even though it was longer and heavier with information. This goes against the grain of conventional wisdom among educators that less able students should not read long, difficult science prose because they "won't get anything out of it." The fact is that less able students as well as able acquired _less_ vocabulary knowledge from reading the shorter, supposedly easier texts. Texts will not necessarily be made easier by making them short and superficial. What is critical that they convey important information precisely, with interconnections fully explained at a level of specificity appropriate for readers who do not know much about the specific subject matter.

The effectiveness of the Elaborated version may be the result of a combination of all the revisions. Results from the present study strongly suggest that revisions in surface features do not affect acquisition of vocabulary knowledge significantly when existing information in a text is anemic. However, improvements in surface features may have been a necessary condition for fuller comprehension. In other words, it may be that incidental word learning is facilitated only when all three types of changes are made in a text. Because an incremental rather than a fully crossed factorial design was used to create the texts in the current study, the separate effects of each type of editorial change cannot be evaluated unambiguously.

In addition to influences of text features, results from the present study suggest that the reader's ability is a factor in incidental acquisition of word knowledge. However, some caution must be taken in interpreting this result because the only other study investigating incidental acquisition of vocabulary knowledge from natural texts that employed students representing a range of ability (Nagy, Herman, & Anderson, 1985b) did not find ability to be a significant influence on learning from context. Perhaps, if students in the present study had been tested a week after reading the texts, ability would not have been significant. Further investigation is needed to assess this possibility.

To put the major conclusion of this study in simple terms, text revisions that only clarify the organization already present do not in and of themselves increase a reader's learning of unfamiliar words. For this to happen, the concepts in the text must be elaborated so that a more complete body of knowledge is presented.

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Table 1

Guidelines for Text Revisions

Guidelines: Macrostructure Revisions

1. Do titles and subtitles reflect the structure and the message of the text?
2. Keeping in mind the purpose of the text, are there any portions of text not in line with such a purpose? Do any portions of text logically belong elsewhere in the text?
3. Are there any portions of the text which are not appropriate for the intended audience because that audience lacks the prior knowledge to understand it? Are technical terms introduced that are not part of the purpose of the text?

Guidelines: Microstructure Revisions

1. Can any relationships be made explicit by adding signal words to alert the reader to comparative, contrastive, sequential, or conditional relationships? Are examples and/or additional instances signaled?
2. Using information already present in the text, can other implicit relationships key to understanding the overall or sectional theme be made explicit by adding phrases, clauses, or sentences?
3. Are there any anaphorisms for which the co-reference is unclear?

Guidelines: Elaborated Revisions

1. After determining key concepts, does the text explain enough about the concept so that the intended audience can readily grasp it? Consider relevant attributes, irrelevant attributes, examples, and non-examples of the concept.
2. If form/function, cause/effect, part/whole relationships are involved, does the text explicitly convey the relationship?
3. Does the text explain how key concepts fit with other concepts and with the overall theme?

Table 2

Examples of Text Versions for River Systems

Original Text

A river carries huge amounts of sediment during floods. When the river spills over its banks, it quickly drops a mound of coarse sediment, forming a levee (LEV ee) parallel to the channel. Fine sediments are carried farther and spread out forming a **floodplain** of swampy, fertile soil. Floodplains include the width of the meander belt but may not extend to the valley walls. The valley is much wider than the river channel at this stage of development.

Macrostructure Version

Sediment may be dropped along the river sides, within the channel, or at the mouth. A river carries huge amounts of sediment during floods. When the river spills over its banks, it quickly drops a mound of coarse sediment forming a levee (LEV ee) parallel to the channel. Fine sediments are carried farther and spread out, forming a **floodplain** of swampy, fertile soil.

Microstructure Version

Sediment may be dropped along the river sides, within the channel or at the mouth. A river carries huge amounts of sediment during floods. First, when the river spills over its banks, it quickly drops a mound of coarse sediment, forming a **levee** (LEV ee) parallel to the channel. In contrast, fine sediments are carried farther and spread out, forming a floodplain of swampy, fertile soil.

Elaborated Version

Sediment may be dropped along the river sides, within its channel or at its mouth. A river carries huge amounts of sediment during floods. First, when a river floods, larger land forms can be created because the river is carrying huge amounts of sediment that can be deposited. When a river spills over its banks, its velocity decreases slightly and the river quickly drops its coarse, heavier sediment in a mound on top of the river banks, forming a natural **levee** (LEV ee) parallel to the river. Such a mound raises the river banks higher, making it harder for the river to overflow its banks during the next flood time. In contrast, finer, light weight sediments are carried farther and spread out over the flooded area next to the river. Eventually after many, many floods deposit layers of such fine sediments, a flat area of swampy, fertile soil called a **floodplain** is formed next to the river.

Table 3

Target Words Ordered by Frequency

River Systems Text		Circulation Text	
Word	SFI	Word	SFI
downpour	--	backflow	--
drainage basin	--	renal	--*
floodplain	--	systemic	--*
headwater	--	ventricle	29.9*
headward extension	--	atrium	30.5*
impermeable	--	carbon dioxide	30.7
oxbow lake	--	excretion	32.6*
slump	--	coronary	33.5*
suspended load	--	aorta	34.6*
thaw	--	portal	36.9*
rills	25.9	exert	36.9
meander	26.0	pulmonary	37.8*
scour	30.2	diffusion	39.1*
irregularity	30.6	circulatory	39.9
levee	31.3	pigment	41.1*
runoff	36.0	intestines	41.7
saturate	39.6	capillary	44.1*
turbulent	40.9	artery	44.8*
elevation	42.5	chamber	45.6
precipitation	43.1	organic	47.2
tributary	43.8	contraction	49.5
porous	43.9	vein	50.3*
divide	**		
bed	**		

Note. SFI = Standard Frequency Index
* = Identified as difficult by all raters
** = SFI unknown because the less frequent meaning is used
-- = Does not occur in Carroll, Davies, and Richman (1971)

Table 4

An Example of a Multiple-Choice Question at Two Levels of Difficulty

---

Easier Question

---

thaw means:

a) a natural hole in the land leading to a cave or underground passageway

b) small stream or brook

c) the degree something slants upward or downward

d) to change from a frozen solid to a liquid by gradual warming

e) don't know

Harder Question

---

thaw means:

a) to move suddenly downward

b) to mix completely with a liquid

c) to change from a frozen solid to a liquid by gradual warming

d) to change from a gas to a liquid or solid

e) don't know

Table 5

Final hierarchical regression analysis performed on the multiple-choice data

Variable	b	% Variance	F
Grand Mean	0.91	13.75	4936.50
Prior Knowledge[a]	22.16	3.12	1126.71
Question Difficulty[d]	7.84	2.92	1053.43
Block Order 1[c]	1.88	0.11	39.71
Day[e]	-1.85	0.11	39.71
Word Source[b]	-0.41	0	< 1
Word Source x Question Difficulty	-3.15	0.34	123.46
Prior Knowledge x Question Difficulty	2.98	0.06	20.94
Ability	-0.01	0	--
Text Student Read[b]	-0.03	0	--
Elaborated Contrast[f]	-0.01	0	--
Learning from Context[g]	2.30	0.64	231.05
Word Source x Ability	0.07	0.09	32.85
Word Source x Elaborated Contrast	-0.46	0.02	6.85
Text Student Read x Elaborated Contrast	-0.25	0	< 1
Text Student Read x Ability	0	0	< 1
Learning from Context x Elaborated Version Contrast	0.61	0.04	12.64
Learning from Context x Ability	0.04	0.03	9.74
Constant/Residual	-9.02	78.77	

Note. Critical value (1, 28371) = 6.63, $p < .01$. Dashes indicate between-subject factors not tested for significance.

[a] Coded +1 know, 0 don't know

[b] Coded +1 river, -1 circulation

[c] Coded +1 first block completed each day: -1 second block completed

[d] Coded +1 easier question, -1 harder question

[e] Coded +1 first day of posttesting, -1 second day

[f] Coded +3 Elaborated Version; -1 all other versions

[g] Coded +1 read, -1 not read

Table 6

Percentage of Words Known by Text Student Read and Word Source

Text Student Read	Word Source River M	 River SD	 Circulation M	 Circulation SD
River	**54**	**55**	47	57
Circulation	43	55	**55**	**58**

Note. Boldface indicates Read; regular type, Not Read.

Table 7

Probabilities of Learning an Unknown Word at Two Levels of Difficulty by Ability

	Level of Difficulty	
Ability	Easier Question	Harder Question
3rd - 30th	.10	.05
31st - 60th	.22	.13
61st - 80th	.26	.12
81st - 99th	.42	.26

Note. Ability represented by comprehension percentiles from the CTBS.

Table 8

Percentage of Words Known by Text Version and by Read and Not Read

	Text Version							
	Original		Macro-structure		Micro-structure		Elaborated	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Read	55	58	55	58	53	58	58	56
Not Read	47	56	45	56	47	57	45	56

Table 9

Probabilities of Learning an Unknown Word at Two Levels of Difficulty for Each Text Version

Text Version	Level of Difficulty Easier Question	Harder Question
Original	.23	.10
Macrostructure	.21	.15
Microstrucutre	.17	.09
Elaborated	.29	.20

Table 10

Percentage of Words Known by Word Source and Text Version

Text Version	River Systems		Circulation	
	M	*SD*	*M*	*SD*
Original	51	57	51	57
Macrostructure	49	56	51	58
Microstructure	49	56	51	58
Elaborated	49	55	54	57

Note. For Read and Not Read.

Table 11

An Example Comparing Explanations of Portal Circulation in the Original and Elaborated Versions

Original Text	Elaborated Version
Portal (PORT uhl) circulation transports blood from the digestive tract and related organs to the systemic circulation. The portal system drains blood from the small intestines, liver, and pancreas. It includes a network of veins that combine to form a single, large portal vein. The portal vein leads to the liver where excess sugar is stored.	The pulmonary circulation adds oxygen to the blood, but it is the portal circulation that adds nutrients. Diffusion of nutrients into the blood occurs as the blood flows by the walls of the small intestines. The portal circulation then carries the nutrient-rich blood to the liver. As the blood flows through the tissues of the liver, the liver changes the nutrients into substances useful to the body and stores other nutrients for future use. From the liver, the nutrient-rich blood returns to the heart to be pumped to the rest of the body.

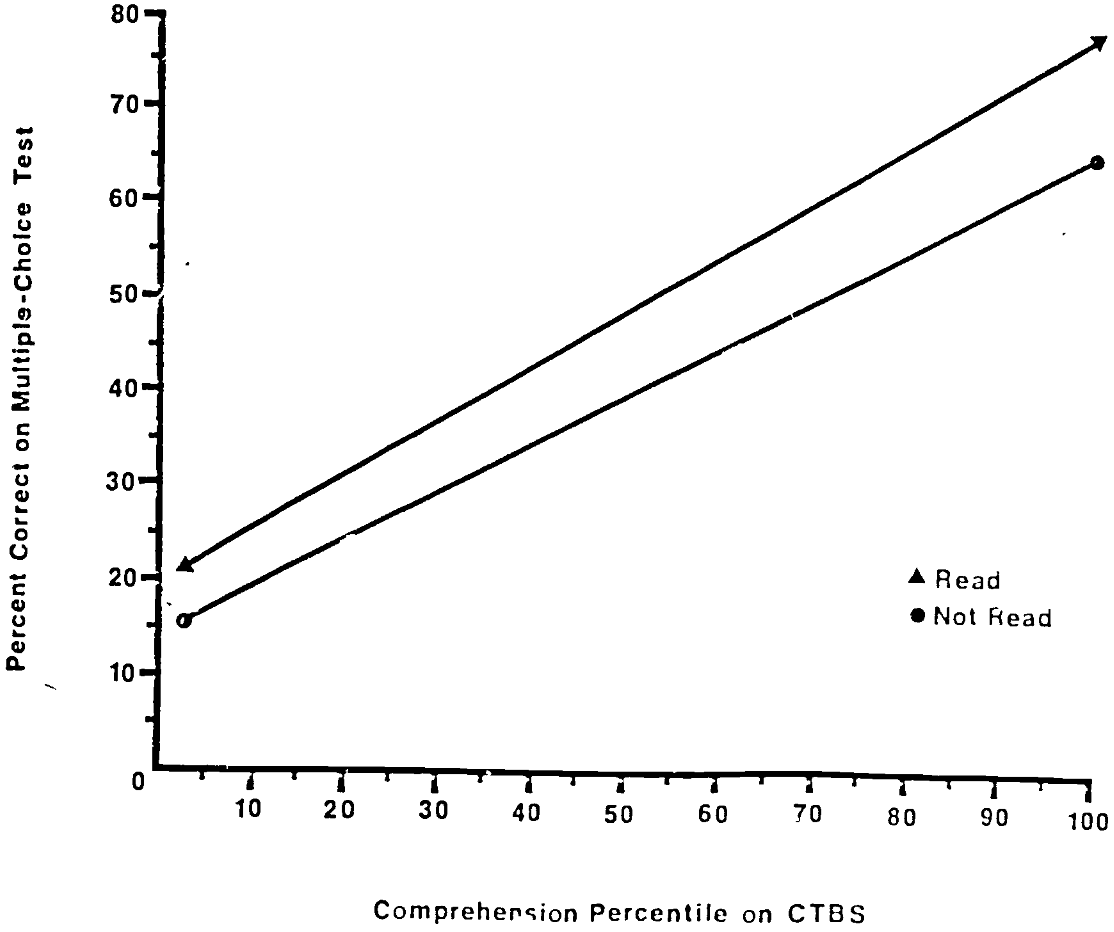

Figure 1. Interaction of learning from context and ability.

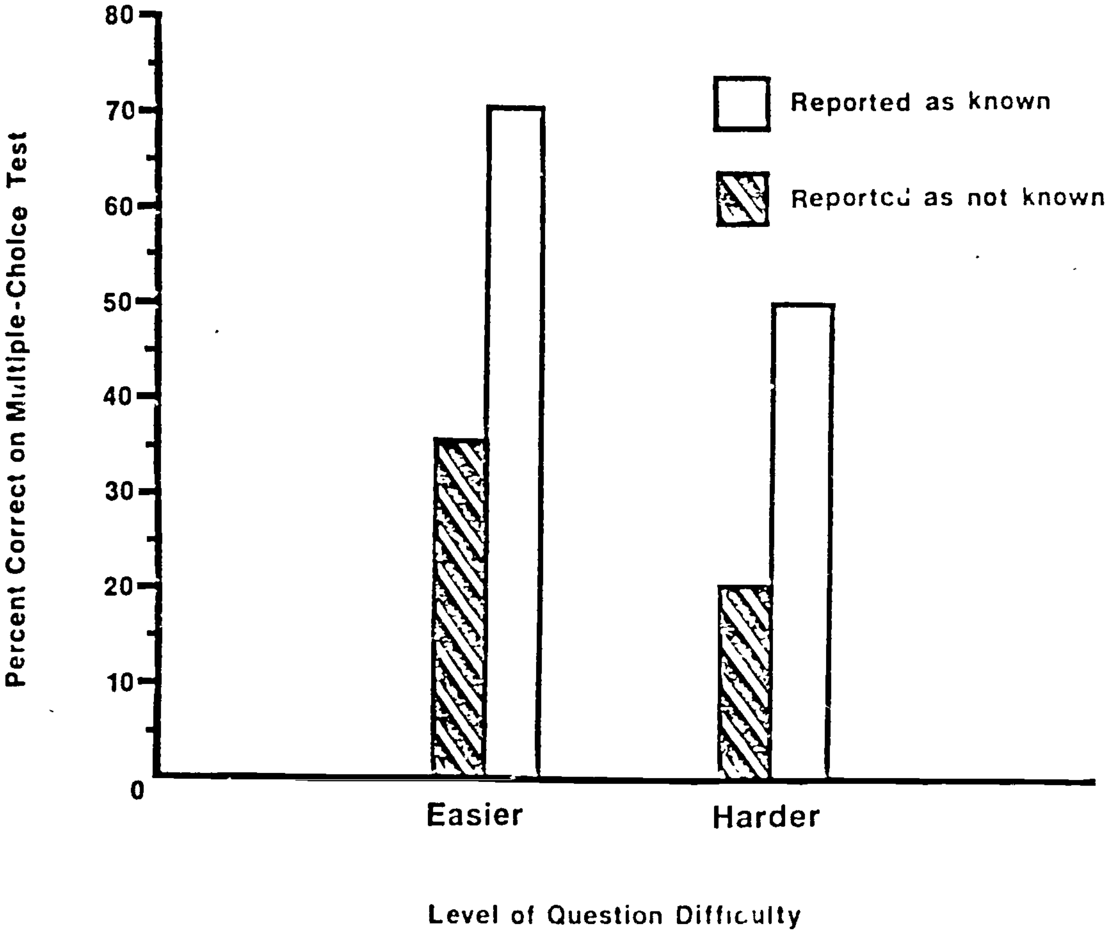

Figure 2. Interaction of prior knowledge and level of question difficulty.

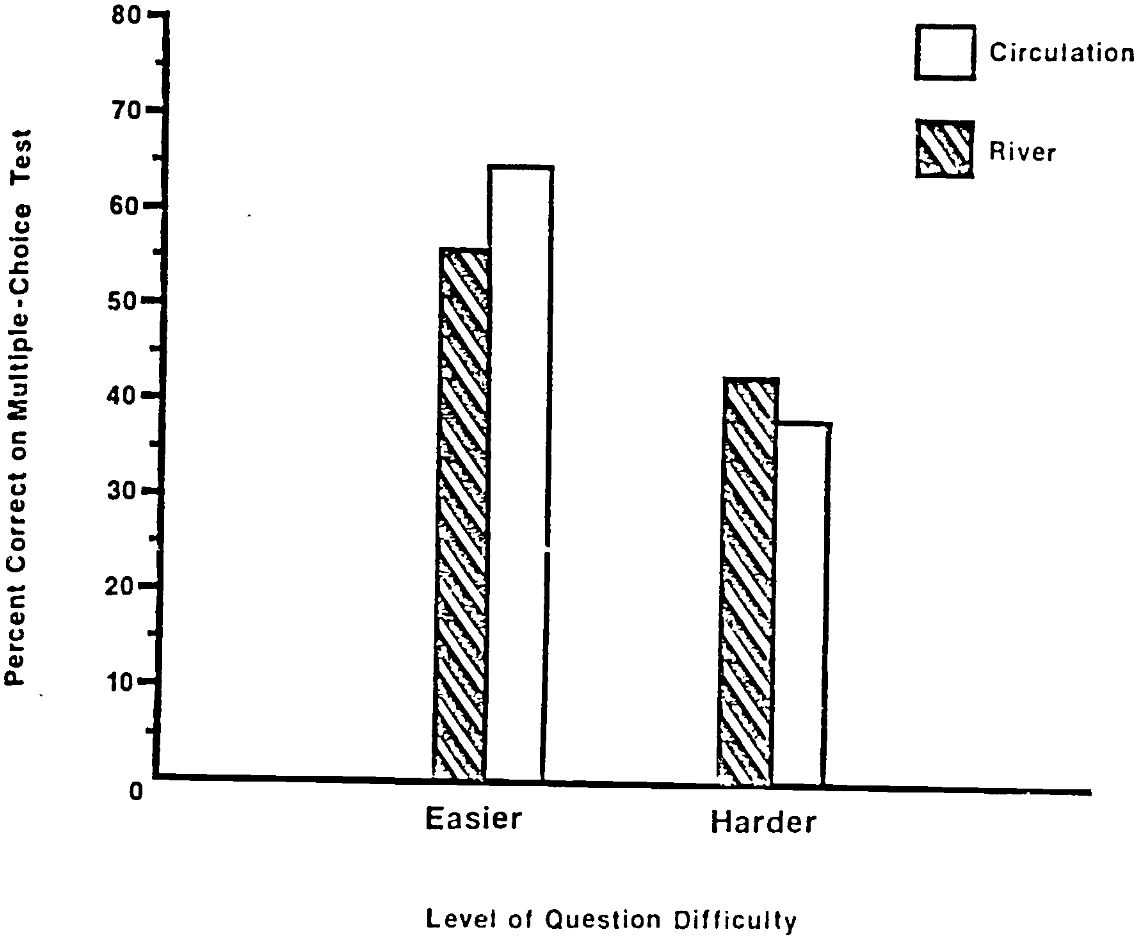

Figure 3. Interaction of word source and level of question difficulty.

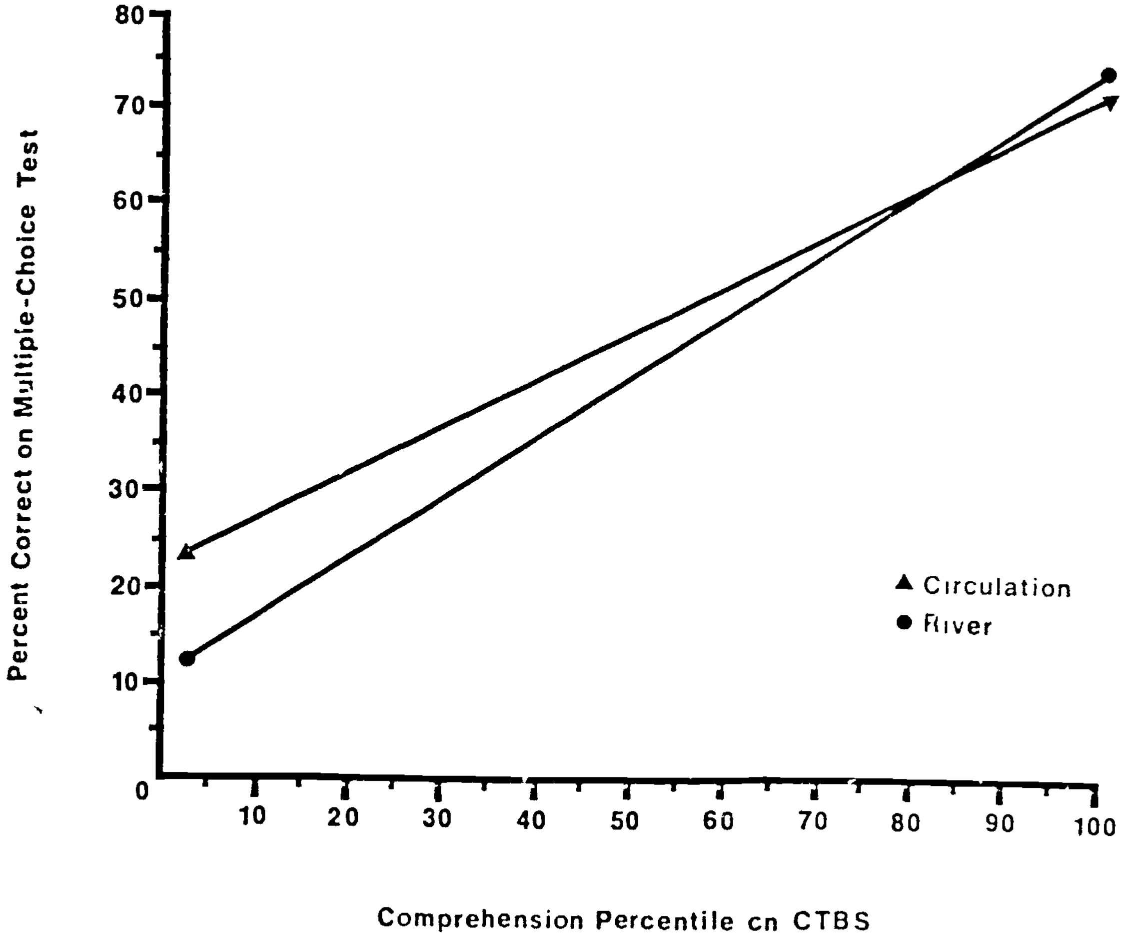

Figure 4. Interaction of word source and ability.

APPENDIX

TEXT VERSIONS

(Original Text)

WATER SYSTEMS

Runoff

Water evaporates from the ocean and then falls on the land. Some precipitation evaporates immediately; some is used by plants and animals; some joins the underground water system. Nearly 40 percent of precipitation flows across the land surface back to the ocean as runoff. The amount of precipitation that becomes runoff depends on the type of land surface, the slope of the land, and the amount of rainfall. Gentle rains and light snows evaporate, sink into the ground, or are used by plants and animals. Heavy fast downpours become runoff. When the ground is saturated by long periods of rain, further precipitation becomes runoff.

Steep slopes shed water quickly. Gentle slopes or flat areas hold water in place until it evaporates or sinks into the ground. Porous rocks at the surface allow water to sink into the ground. Impermeable (ihm PUR mee uh bul) rocks cause rapid runoff.

During warm weather, evaporation decreases runoff. During cold weather, precipitation may be trapped as snow or ice. If thawing is fast, the amount of runoff is large. Tree roots, brush, and grass hold soil and water in place where it sinks into the ground or is used by vegetation.

Development of River Systems

Rivers are the most important erosional agent because they affect so much area. Landscapes are largely the work of running water, even in desert regions. River systems begin when runoff follows the same channel rainfall after rainfall. Because of gravity, water continuously flows towards lower levels. Runoff follows the shortest path downward unless the material is too resistant for it to cut through. The flow then turns aside and cuts a path around the resistant obstacle. Once established, the same path is used by all later runoff.

Small **rills** form first. They join to form creeks, which join to form streams, which join to form the **main river**. This network of channels is a drainage **system**. Many drainage systems have a treelike pattern. A main river like the Mississippi is the tree trunk. **Tributaries** (TRIHB yuh ter ees) like the Missouri and Ohio Rivers are large branches. Rills are the small branches and twigs. The river mouth is where a river empties into another river, a lake, or the ocean.

The area drained by a main river and its branches is a drainage basin. Drainage basins are separated from one another by high ground called the divide. In early stages divides are wide, but they become narrow in time. Sometimes a drainage system cuts through its divide and steals runoff from another drainage basin.

A drainage sytem grows larger through headward extension, by deepening its channels, and by widening its valleys. Water flows from high elevations as a sheet which gradually is channeled into a network of small rills. These rills eventually extend higher and higher into the headwater area. Downstream rills join to become tributaries. Runoff and mass movements along the channel carry sediment to the river. The sediment is used to scour the river channel deeper and wider.

In time, a river reaches a balance between the processes of erosion and deposition. Then a river has a profile of equilibrium (ee kwuh LIHB ree um) along its length. This profile does not change as long as conditions stay the same, and the river's velocity is just right to carry its load of sediment. The river adjusts its profile, however, to any changes in the drainage basin. Each tributary within a drainage system develops its own profile. It has a history that may be different from all the other tributaries.

Drainage systems may be changed by any of the following: uplift or lowering of the headwater area where the river begins; uplift or lowering of sea level; changes in climate; or wearing down of the divide.

Erosion by Rivers

Whether or not a stream erodes its bed depends on its velocity and the size of the load it is carrying. In turn, velocity depends on the slope of the riverbed and on the volume of water. During flood periods, the velocity of a river increases because of increased volume. Water dashing against the bed and sides of the river channel erodes it very rapidly. Rivers flow to lower elevations in a turbulent fashion. As water tumbles down, rises, and tumbles down again, it picks up fragments from the bed and sides. These fragments, in turn, are dashed against the bottom and sides for further scouring action.

Sediment picked up from the bed and sides becomes the suspended load of a river. The bed load is material rolled along the bottom because it is too large and heavy to be picked up. All materials are ground finer as they are carried or rolled along. Some material is removed from the bed and sides by solution.

If a river channel is cut into resistant rock, the channel will be deep and narrow. If the channel walls are soft, the material slumps down into the river and is carried away. In time, mass movements widen the valley far beyond the river channel itself. As a drainage system becomes large and well developed, rivers begin to meander (mee AN dur). This means they wander from side to side. Meandering sometimes begins because of an obstacle or irregularity in the channel. Meandering ususally starts where the river profile flattens out.

The velocity of a river usually is fastest at the center, away from friction with sides or bottom. As a river meanders, the velocity increases on the outside and decreases on the inside of the curves. Erosion on the outside of the curve removes about the same amount of sediment that is deposited on the inside of the curve. Meander curves widen and move down stream in time. As floodwater spills from one meander to the next, across a narrow neck of land, a meander may be abandoned to become an oxbow lake. Eventually, the lake fills with vegetation.

River Deposits

Runoff erodes the land about 0.3 meters in 9000 years. One fourth of this sediment reaches the ocean. The rest remains within the drainage basin. Small tributaries carry little sediment and seldom deposit their load. At lower levels, a river may be carrying all the sediment possible. A small decrease in velocity causes a stream to deposit this sediment. Sediment may be dropped along the river sides, within the channel, o at the mouth.

A river carries huge amounts of sediment during floods. When the river spills over its banks, it quickly drops a mound of coarse sediment, forming a levee (LEV ee) parallel to the channel. Fine sediments are carried farther and spread out forming a floodplain of swampy, fertile soil. Floodplains include the width of the meander belt but may not extend t' the valley walls. The valley is much wider than the river channel at this stage of development.

Many streams deposit sediment within their channels during dry seasons. This material is swept out during floods, but more is deposited in the next dry period. Rivers deposit sediment at their mouths if they empty into a quiet body of water. The river flow splits into a number of channels which may become filled with sediment as water loses its velocity. New channels then form and spread the sediment out in the form of a fan or delta. Most deltas extend out into open water for many kilometers. Sediment from the Mississippi river has formed five large deltas in the last 5000 years. The river also has supplied sediment for many of the shore features along the Louisiana and Texas coasts.

(Macrostructure Version)

WATER SYSTEMS

How River Systems Develop and Change the Land

How Precipitation Becomes Runoff

Water evaporates from the ocean and then falls on the land. Some precipitation evaporates immediately; some is used by plants and animals; some joins the underground water system. Nearly 40 percent of precipitation flows across the land surface back to the ocean as runoff.

The amount of precipitation that becomes runoff depends on the type of land surface, the slope of the land, the amount of rainfall, and the temperature. Porous rocks at the surface allow water to sink into the ground. Impermeable (ihm PUR mee uh bul) rocks cause rapid runoff. Steep slopes shed water quickly. Gentle slopes or flat areas hold water in place until it evaporates or sinks into the ground. Gentle rains and light snows evaporate, sink into the ground, or are used by plants and animals. Heavy fast downpours become runoff. When the ground is saturated by long periods of rain, further precipitation becomes runoff. During warm weather, evaporation decreases runoff. During cold weather, precipitation may be trapped as snow or ice. If thawing is fast, the amount of runoff is large.

How River Systems Develop From Runoff

River systems begin when runoff follows the same channel rainfall after rainfall. Because of gravity, water continuously flows towards lower levels. Runoff follows the shortest path downward unless the material is too resistant for it to cut through. The flow then turns aside and cuts a path around the resistant obstacle. Once established, the same path is used by all later runoff.

A river system has several parts. Small rills form first. They join to form creeks, which join to form streams, which join to form the main river. The river mouth is where a river empties into another river, a lake, or the ocean. This network of channels is a drainage system.

Many drainage systems have a treelike pattern. A main river like the Mississippi is the tree trunk. Tributaries (TRIHB yuh ter ees) like the Missouri and Ohio Rivers are large branches. Rills are the smallest branches and twigs.

The area drained by a main river and its branches is a drainage basin. Drainage basins are separated from one another by high ground called the divide.

How River Systems Change Over Time

Erosion and deposition change the length and shape of river systems over time. A drainage system grows larger through headward extension, by deepening its channels, and by widening its valleys. Drainage systems may be changed by any of the following: uplift or lowering of the headwater area where the river begins; uplift or lowering of sea level; or wearing down of the divide. Many of these changes in a river system are the result of erosion from runoff.

River erosion. Runoff can erode the sides and bottom of river channels. Whether or not a stream erodes its bed depends on its velocity and the size of the load it is carrying. In turn, velocity depends on the slope of the riverbed and on the volume of water. During flood periods, the velocity of a river increases because of increased volume. Rivers flow to lower elevations in a turbulent fashion. Water dashing against the bed and sides of the river channel erodes it very rapidly. As water tumbles down, rises, and tumbles down again, it picks up fragments from the bed and sides. These fragments, in turn, are dashed against the bottom and sides for further scouring action.

Sediment picked up from the bed and sides becomes the suspended load of a river. The bed load is material rolled along the bottom. All materials are ground finer as they are carried or rolled along.

Runoff and mass movements along the channel carry sediment to the river. If the channel walls are soft, the materials slumps down into the river and is carried away. In time, mass movements widen the valley far beyond the river channel itself.

Erosion can change the length of a river near its beginning. Water flows from high elevations as a sheet which gradually is channeled into a network of small rills. These rills eventually extend higher and higher into the headwater area. Sometimes a drainage system cuts through its divide and steals runoff from another drainage basin.

Farther downstream, erosion can change the shape of a river. As a drainage system becomes large and well developed, rivers begin to meander (mee AN dur). This means they wander from side to side. Meandering sometimes begins because of an obstacle or irregularity is in the channel.

Once meandering begins, the velocity of the river can change the meanders. The velocity of a river usually is fastest at the center, away from friction with sides or bottom. As a river meanders, the velocity increases on the outside and decreases on the inside of the curves. Erosion on the outside of the curve removes about the same amount of sediment that is deposited on the inside of the curve. Meander curves widen and move down stream in time. As floodwater spills from one meander to the next, across a narrow neck of land, a meander may be abandoned to become an **oxbow lake**.

River deposits. Other changes in a river system are the result of deposits of materials eroded from the land. Runoff erodes the land ever so slowly--in some places about 0.3 meters in 9000 years. One fourth of this sediment reaches the ocean. The rest remains within the drainage basin. Small tributaries carry little sediment and seldom deposit their load. At lower levels, a river may be carrying all the sediment possible. A small decrease in velocity causes a stream to deposit this sediment.

Sediment may be dropped along the river sides, within the channel, or at the mouth. A river carries huge amounts of sediment during floods. When the river spills over its banks, it quickly drops a mound of coarse sediment, forming a **levee** (LEV ee) parallel to the channel. Fine sediments are carried farther and spread out forming a floodplain of swampy, fertile soil.

Many streams deposit sediment within their channels during dry seasons. This material is swept out during floods, but more is deposited in the next dry period.

Rivers deposit sediment at their mouth if they empty into a quiet body of water. The river flow splits into a number of channels which may become filled with sediment as water loses its velocity. New channels then form and spread the sediment out in the form of a fan or delta. Most deltas extend out into open water for many kilometers. Sediment from the Mississippi river has formed five large deltas in the last 5000 years. In conclusion, runoff develops river systems and changes the land over which it flows.

(Microstructure Version)

WATER SYSTEMS

How River Systems Develop and Change the Land

How Precipitation Becomes Runoff

Water evaporates from the ocean and then falls back on the land in some form of precipitation. Some precipitation evaporates immediately; some is used by plants and animals; some joins underground water systems. But, nearly 40 percent of precipitation that falls on the land becomes runoff which flows across the land surface back towards the ocean.

The amount of precipitation that becomes runoff depends on the type of land surface, the slope of the land, the amount of rainfall, and the temperature. First, if the land surface has porous rocks, then the rocks allow water to sink into the ground. However, if the land surface has impermeable (ihm PUR mee uh bul) rocks, then rapid runoff occurs.

Second, if the land has steep slopes, then water sheds quickly. But, gentle slopes or flat areas of land hold water in place until it evaporates or sinks into the ground.

Third, the amount of runoff depends on the amount of rainfall. Gentle rains and light snows evaporate, sink into the ground, or are used by plants and animals. But, heavy fast downpours become runoff. Furthermore, when the ground is saturated by long periods of rain, any further precipitation becomes runoff. If thawing is fast, the amount of runoff is large also.

Fourth, during warm weather evaporation decreases runoff. During cold weather, precipitation may be trapped as snow or ice. When thawing is fast, the amount of runoff is large.

How River Systems Develop From Runoff

River systems begin when runoff follows the same channel rainfall after rainfall. Because of gravity, water continuously flows towards lower levels. Runoff follows the shortest path downward unless the material is too resistant for it to cut through. The flow then turns aside and cuts a path around the resistant obstacle. Once established, the same path is used by all later runoff.

A river system has several parts. Many runoff paths or channels exist in a river system. Small channels called **rills** form first. As rills flow downward, some join to form creeks. Further down, creeks join to form streams. At still lower levels, streams join to form the main river. The river **mouth** is where a river empties into another river, a lake, or the ocean. This network of runoff channels is a drainage system.

Many drainage systems have a treelike pattern. Think of a main river like the Mississippi as the tree trunk. Tributaries (TRIHB yuh ter ees) like the Missouri and Ohio Rivers are the large branches. Smaller tributaries like rills are the smallest branches and twigs.

The area drained by a main river and its branches is a drainage basin. Drainage basins are separated from one by another by high ground called a **divide**.

How River Systems Change Over Time

Erosion and deposition change the length and the shape of river systems over time. A drainage system grows larger through headward extension, by deepening its channels and by widening its valleys. Furthermore, drainage systems may be changed by any of the following: uplift or lowering of the headwater area where the river begins; uplift or lowering of sea level; or wearing down of the divide. Many of these changes in a river system are the result of erosion from runoff.

River erosion. Runoff can erode and change the sides and bottom of a river channel. Whether or not a river erodes its bed depends on its velocity and the size of the load it is carrying. In turn, velocity depends on the slope of the riverbed and the volume of runoff. During flood periods, the velocity of a river increases because of increased volume. Rivers flow to lower elevations in a turbulent fashion. Water dashing against the bed and sides of the river channel erodes it very rapidly. As water tumbles down, rises, and tumbles down again, it picks up fragments from the bed and sides. These fragments, in turn, are dashed against the bottom and sides of the river for further scouring action.

Sediment picked up from the bed and sides becomes the suspended load of a river. In contrast, the bed load is material rolled along the bottom. All materials are ground finer as they are carried or rolled along.

Sediment is carried to the river by runoff and mass movements along its channel. If the channel walls are soft, the material slumps down into the river and is carried away. In time, mass movements widen the valley far beyond the river channel itself.

Erosion can change the length of a river near its beginning. Precipitation flows from high elevations as a sheet which gradually is channeled into a network of small rills. These rills eventually extend higher and higher into the headwater area. Sometimes a drainage system cuts through its divide and steals runoff from another drainage basin.

Farther downstream, erosion can change the shape of a river. As a drainage system becomes large and well developed, rivers begin to meander (mee AN dur). This means they wander from side to side. Meandering sometimes begins because an obstacle or irregularity is in the channel.

Once meandering begins, the velocity of the river can change the meanders. The velocity of a river usually is fastest at the center, away from friction with sides and bottom. However, as a river meanders, its velocity increases on the outside and decreases on the inside of the curves. Erosion on the outside of the curve removes about the same amount of sediment that is deposited on the inside of the curve. Meander curves widen and move downstream in time. As floodwater spills from one meander to the next, across a narrow neck of land, a meander may be abandoned to become an oxbow lake.

River deposits. Other changes in a river system are the result of deposits of materials eroded from the land. Runoff erodes the land ever so slowly--in some places about 0.3 meters in 9000 years. One fourth of this sediment from land erosion reaches the ocean. The rest of the sediment remains within the drainage basin. For example, small tributaries carry little sediment, and seldom deposit their load. However, at lower levels a main river may be carrying all of the sediment possible. Then if a small decrease in velocity occurs, the river deposits its sediment.

Sediment may be dropped on the land next to a river, within the channel or at the mouth. A river carries huge amounts of sediment during floods. First, when the river spills over its banks, it quickly drops a mound of coarse sediment, forming a levee (LEV ee) parallel to the channel. In contrast, fine sediments are carried farther and spread out forming a floodplain of swampy, fertile soil next to the river.

Second, many streams deposit sediment within their channels during dry seasons. This material is swept out during floods, but more is deposited in the next dry period.

Third, rivers deposit sediment at their mouth if they empty into a quiet body of water. The river flow splits into a number of channels which later may become filled with sediment if the water loses its velocity. New channels then form and spread the sediment out in the form of a fan or delta at the river mouth. Most deltas extend out into the open water for many kilometers. For example, sediment from the Mississippi river has formed five large deltas in the last 5000 years. In conclusion, runoff develops river systems and changes the land over which it travels.

(Elaborated Version)

WATER SYSTEMS

How River Systems Develop and and Change the Land

How Precipitation Becomes Runoff

Water evaporates from the earth's surface (mainly from the ocean) and then falls back on the land in some form of precipitation (rain, snow, and so on). Some precipitation evaporates immediately; some is used by plants and animals; some joins underground water systems. But, nearly 40 percent of precipitation that falls on the land becomes runoff which flows across the land surface back towards the ocean. This runoff is the main source of water in streams and rivers.

The amount of precipitation that becomes runoff depends on the type of land surface, on the slope of the land, on the amount of rainfall, and on the temperature. First, if the land surface has porous rocks, the rocks allow rainwater to sink through them and into the ground with little or no runoff occurring. However, if the land surface has impermeable (ihm PUR mee uh bul) rocks, then rainwater cannot sink through them, and rapid runoff occurs.

Second, if the land has steep slopes, then rainwater sheds so quickly that most of the water flows downhill as runoff. But, little runoff occurs on gentle slopes or flat areas of land that hold water in place until it evaporates or sinks into the ground.

Third, the amount of runoff depends on the amount of rainfall. Gentle rains and light snows do not become runoff because they evaporate, sink into the ground, or are used by plants and animals. But, heavy fast downpours become runoff because the large volume of rainwater does not have time to sink into the ground or evaporate. Furthermore, when the ground is saturated from long periods of rain, there is so much water already in the ground that any further precipitation becomes runoff.

Fourth, during warm weather when much precipitation evaporates, a smaller amount of runoff occurs. Not much runoff occurs during cold weather either when precipitation may be trapped as snow or ice. When thawing of snow and ice is fast because of suddenly warm temperatures, the amount of runoff can be large. Without runoff from precipitation, the earth would have no river systems.

How River Systems Develop From Runoff

River systems begin when runoff follows the same channel rainfall after rainfall. Because of gravity, water continuously flows towards lower levels. Runoff follows the shortest path downward unless the material is too resistant for it to cut through. The flow then turns aside and cuts a path around the resistant obstacle, such as a huge rock. Once established, the same path is used by all later runoff.

A river system has several parts. Many runoff paths or channels exist in a river system. Small channels called rills form first, generally at the beginning of the river. Rills are tiny enough to step over. As rills flow downward, some join, flowing together to form creeks. Further down, some creeks flow together to form streams. At still lower levels, streams join to form the main river. The mouth of the river is the place where a river empties into another river, a lake, or the ocean. For example, the mouth of the Ohio river is where it empties into the Mississippi river. Since a river system drains runoff from the land, this network of channels flowing together can also be called a drainage system.

Many drainage systems have a treelike pattern if viewed from far above the earth's surface. Think of a main river like the Mississippi as the tree trunk. The big tributaries (TRIHB yuh ter ees) like the Missouri and Ohio Rivers which flow into the Mississippi are the large branches. The smaller tributaties like rills and streams are the smallest branches and twigs. This network of runoff channels is a drainage system.

The area of land drained by a main river and its branches is a drainage basin. The huge Mississippi drainage basin, for example, drains runoff from land in 31 states. Drainage basins are separated from one another by high ground called a divide. When precipitation falls on a divide, runoff is separated by the high ground and flows down opposite sides of the high ground into two different river systems.

How River Systems Change Over Time

Erosion and deposition change the length and shape of river systems over time. A drainage system grows larger through headward extension, by deepening its channels and by widening its valleys. Furthermore, drainage systems may be changed by any of the following: uplift or lowering of the headwater area where the river begins; uplift or lowering of sea level; or wearing down of the divide. Many of these changes in a river system are the result of erosion from runoff.

River erosion. Runoff can erode and change the sides and bottom of a river channel, carrying sediment into the river. Sediment is fragments of soil, rock, vegetation and other particles mixed into the river water often making the water appear muddy. As the sediment is carried along in the river, it acts like a tool scouring and eroding the river channel deeper and wider.

Whether or not a stream erodes its bed depends on the velocity of the water and the amount of sediment or the load being carried in the water.

In turn, velocity depends on the slope of the riverbed and the volume of runoff. During flood periods, the velocity of a river increases because of the increased volume of water. Rivers flow to lower elevations in a turbulent fashion. Water dashing against the bed and sides of the river channel erodes it very rapidly. As water tumbles down, rises, and tumbles down again, it picks up fragments from the bed and sides adding more sediment to the river. When these fragments of sediment are dashed against the bottom and sides of the river, the fragments are ground finer, creating further scouring action and even more erosion. Thus, the slope of the riverbed, the velocity of its water and the amount of fragments or sediment being carried in its water work together to erode the sides and bottom of the river, thus making the river deeper and wider.

Sediment picked up from the bed and sides becomes the suspended load of a river. In contrast, the bed load is material rolled along the bottom because it is too heavy to be picked up (stones, pebbles and so on). All materials are ground finer as they are carried or rolled along.

Sediment is carried to the river by runoff and mass movements along its channels. If the channel walls are soft, the flowing river water easily erodes the walls and the earth slumps down into the river and is carried away as sediment. In time, mass movements, such as huge chunks of earth falling into the river, widen the valley far beyond the river channel itself.

Erosion can change the length of a river near its beginning. Precipitation flows from high elevations as a sheet of rainwater which is gradually channeled into a network of small rills. Ground near the beginning of these small channels is slowly washed away. The result of this erosion is that rills eventually extend higher and higher into the headwater area and rivers grow longer. Every now and then, such headward extension cuts through a divide. After a cut has occurred, precipitation that used to flow to a river on the west side of the divide, for example, is now captured in the cut and flows to another river system on the east side. Because of this cut, the river on the east side steals runoff from the river on the west side.

Farther downstream erosion can change the shape of a river. As a drainage system becomes large and well developed, rivers begin to meander (mee AN dur). This means the river current flows against one side of its channel, then crosses over and flows against the opposite side of its channel. Meandering sometimes begins because an obstacle, such as a huge rock, or an irregularity is in the channel and the river must curve to flow around it.

Once meandering begins, the velocity of the river can change the shape of the river by eroding the river banks next to the meander curves. The velocity of a river usually is fastest at the center, away from the friction with sides and bottom. However, as a river meanders, its velocity shifts and increases on the outside of the curves and decreases on the inside of the curves. Because river water flows more rapidly against the outside of the curve, land next to that curve is eroded. Such erosion adds much sediment to the river. When the river water carries this sediment by the inside of a curve, some of the sediment is deposited because the decrease in velocity allows the sediment to settle down onto the riverbed. Sediment is constantly being eroded from the outside edge of curves and deposited on the inside curves, eventually creating large bends in the river called meanders. Meander curves can widen and move downstream in time.

During floods, as floodwater spills from one meander to the next, the main river current sometimes flows across the narrow neck of land in the bends. When this happens, the main river can change its channel by continuing to flow through the new channel cut across the narrow neck of land. The river then abandons its old channel through the meander curve. The water left in the adandoned meander becomes an oxbow lake.

River deposits. Other changes in a river system are the result of deposits of materials (sediment) eroded from the land. Runoff erodes the land ever so slowly—in some places about 0.3 meters in 9000 years. One fourth of this sediment is carried in the river water and eventually reaches the ocean. The rest of the sediment remains in the drainage basin where it is deposited. Deposition occurs when the velocity of a river decreases. The amount of sediment deposited depends on the size of the suspended load in the river. For example, small tributaries such as rills, which carry little sediment, seldom deposit their suspended load. However, at lower levels a main river may be carrying all of the sediment possible. Then a small decrease in velocity causes the river to deposit its sediment. Over a period of time, new land forms are created from this deposited sediment.

Sediment may be dropped on the land next to the river, within its channel or at its mouth. A river carries huge amounts of sediment during floods. First, when a river floods, larger land forms can be created since the river is carrying huge amounts of sediment that can be deposited. When a river spills over its banks, its velocity decreases slightly and the river quickly drops its coarse, heavier sediment in a mound on top of the river banks, forming a natural levee (LEV ee) parallel to the river. Such a mound raises the river banks higher, making it harder for the river to overflow its banks during the next flood time. In contrast, finer, light weight sediments are carried farther and spread out over the flooded area next to the river. Eventually after many, many floods deposit layers of such fine sediments, a flat area of swampy, fertile soil called a floodplain is formed next to the river.

Second, many streams deposit sediment within their channels during dry seasons. For example, sandbars or low islands made of sediment can be created if enough sediment is deposited on the riverbed. This material is swept out during floods, but more is deposited in the next dry period.

Third, rivers deposit sediment at their mouth if the rivers empty into a quiet body of water. Because the river's velocity decreases as it flows through its mouth into the quiet water, its suspended load gradually settles down to the bottom. Over time, this deposited sediment builds up and forms an obstacle in the river's mouth. In order to get around the mound of deposited sediment, the river flow splits, branching out in new channels. These channels, in turn, may later become filled with sediment when the water loses its velocity. Then the river flow splits again into even .op more channels. Because of sediment being deposited and the river flow separating, sediment is slowly spread out, forming a fan-shaped area of land at the river mouth called a delta. For example, sediment from the Mississippi river has formed five large deltas in the last 5000 years. In conclusion, runoff carves out river systems to drain precipitation off the land and changes the land over which the runoff flows from the head of a river system to its mouth.

(Original Text)

CIRCULATION

The Heart

A human heart is a cone-shaped, muscular organ about the size of a large fist. The heart is located in the center of the chest behind the breastbone and between the lungs.

A human heart contains four chambers--right atrium (AY tree uhm), left atrium, right ventricle (VEN trih kuhl), and left ventricle. Right and left refer to the body's right and left sides. A wall separates the chambers on the right from the chambers on the left. A valve separates each atrium from the ventricle below it.

The tip of the heart points toward the left side of the body. The beat of the heart is strongest in the tip. This is why you are most likely to feel the heart's beat on the left side of your chest.

To stay alive, your heart must pump constantly. Pumping is produced by alternate contractions and relaxations of the atria and ventricles. A heart contracts more than three billion times during a normal lifetime! The human heart beats between 60 and 80 times per minute. This rate is slightly faster than one beat per second. A woman's heart beats about six to eight beats per minute faster than a man's heart. An infant's heartbeat at birth may be as high as 130 beats per minute.

With each beat, the heart pumps about 130 ml of blood. In one minute, it pumps about 5 l. The work done by the heart each minute is about equal to lifting 32 kg a distance of 30 cm off the ground.

Arteries and Veins

Arteries and veins are two kinds of blood vessels. Arteries (AR ter eez) carry blood away from the heart. Veins (VAYnz) carry blood to the heart. An artery has a thicker wall and smaller inside diameter. The walls of veins are thin and contain less muscle tissue.

Blood in the arteries is under great pressure and moves more rapidly. Blood is forced into the arteries each time the ventricles contract. You can feel a movement in your wrist every time the arteries stretch and fill with blood. The stretching of the artery wall is called a pulse. Each beat of the heart causes a pulse in an artery. The heart and artery keep perfect time. Your pulse has the same rhythm as your heartbeat. At what places on the surface of your body can you locate a pulse?

The walls of arteries assist in pumping blood. Blood is pumped in them. The walls expand and contract. An artery exerts a pumping force when it contracts. Thus, the large arteries help move blood through the body.

Veins have cuplike valves. This prevents the backflow of blood. These valves keep the blood flowing toward the heart.

Veins carry dark red blood low in oxygen. The veins visible in your skin do not appear dark red. They are blue. Pigment in your skin and veins makes the vessels appear blue. Where in the surface of your body can you locate veins?

Blood pressure in the arteries ranges from 110 to 150 mm of mercury. Pressure is about 80 mm when the heart relaxes. Changes in blood volume, flexibility of blood vessels, and rate of heartbeat may affect blood pressure. Blood pressure is a good indicator of a person's health. Abnormal blood pressure may indicate disease or some disorder.

Capillaries

Capillaries (KAP uh ler eez) are tiny blood vessels that connect arteries and veins. They are visible only with a microscope. Capillaries are the most numerous and smallest blood vessels. They have a diameter about equal to the size of a red blood cell, about 0.0075 mm. Red blood cells pass through the smallest capillaries in single file.

Materials go back and forth between the capillaries and the tissues. Diffusion of food and oxygen from the blood to the tissues occurs in the capillaries. White cells can also leave the capillaries. They enter the tissues by squeezing between the cells of the capillary walls. Waste materials move in the opposite direction. Wastes then enter the capillaries. They are carried away for excretion.

Capillaries help control the amount of heat lost from the body. During exercise, capillaries in the skin expand bringing more warm blood to the body surface. The body is cooled as heat from the blood escapes to the environment. When air temperature is low, capillaries in the skin contract. This reduces the flow of blood to the skin and decreses heat loss from the body.

Circulation of the Blood

Blood circulates through three main pathways. These pathways are the pulmonary (PUHL muh ner ee) circulation, the coronary (KOR uh ner ee) circulation, and the systemic (sis TEM ik) circulation. These pathways make up the circulatory (SUHR kyuh luh tor ee) system. The flow of blood through the heart and to and from the lungs is the pulmonary circulation. Blood enters the right atrium from the large veins. Contraction of the atrium forces the blood into the right ventricle. A valve separating the right atrium from the right ventricle is very important. It prevents the blood from returning to the atrium. How? Its construction allows the valve to open only in the direction of the ventricle. [illegible] pushes against the valve in the direction of the atrium, the valve is forced closed. No blood passes through!

Contraction of the right ventricle forces blood from the heart into the pulmonary artery. Blood travels through the pulmonary artery to the lungs and into the lung capillaries. There it picks up oxygen and loses carbon dioxide. The oxygen-rich blood travels through the pulmonary vein back to the left atrium of the heart.

Blood is pumped from the left atrium of the heart to the left ventricle. A valve prevents the blood from going back into the atrium. Blood is pumped out of the left ventricle into the aorta (ay ORT uh). The aorta is the largest artery in the bod The left ventricle exerts more force than any other chamber.

A stethoscope (STETH uh skohp) is used to hear the heartbeat. The heartbeat has two sounds--"lub" and "dub." The "lub" sound is the ventricles contracting and the valves closing. When the ventricles relax, a "dub" sound is heard. The dub sound is produced by the closing of the valves at the entrance to the aorta. The atria and ventricles contract and force blood through the arteries and veins. Then they relax and fill with blood.

The coronary circulation is the movement of blood through the heart tissues. Two main coronary arteries leave the aorta. They curve downward on each side of the heart. Smaller arteries then branch off and enter the heart tissue. These arteries lead to capillaries which carry blood to the tissues. Coronary capillaries join to form coronary veins. Coronary veins empty the blood into the right atrium.

One type of heart attack is caused by the formation of a blood clot in the coronary artery. The clot blocks the artery and prevents the flow of blood. The affected heart muscle may become damaged. Many people survive heart attacks. Their damaged heart is slowly repaired by the growth of scar tissue.

Systemic circulation includes blood vessels that go to and from the heart. It also includes the capillaries in the tissues and the coronary circulation but does not include the pulmonary circulation. Systemic circulation supplies most of the body tissues with nutrients and oxygen.

Renal (REEN uhl) circulation is part of the systemic circulation. The renal circulation includes vessels to and from the kidneys. Kidneys remove mineral waste, organic waste, and excess water from the blood. A separate renal artery branches from the aorta to each kidney. Capillaries then weave their way through the kidneys. These capillaries join to form the renal veins. Renal veins return blood to the major veins.

Portal (PORT uhl) circulation transports blood from the digestive tract and related organs to the systemic circulation. The portal system drains blood from the small intestines, liver, and pancreas. It includes a network of veins that combine to form a single, large portal vein. The portal vein leads to the liver where excess sugar is stored.

(Macrostructure Version)

HUMAN BLOOD CIRCULATION

How the Heart Pumps Blood

The heart is the part of the circulatory system that pumps blood throughout the body. The heart is located in the center of the chest behind the breastbone and between the lungs. The human heart is a cone-shaped, muscular organ about the size of a large fist.

A human heart contains four chambers--right atrium (AY tree uhm), left atrium, right ventricle (VEN trih kuhl), and left ventricle. (Right and left refer to your body's right-hand and left-hand sides). A wall separates the chambers on the right from the chambers on the left. A valve separates each atrium from the ventricle below it.

Here is how each side of the heart pumps blood. Blood from the body enters an atrium. Contraction of an atrium forces blood into a ventricle. The valve separating an atrium from a ventricle is very important. It prevents the blood from returning to an atrium. How? Its construction allows the valve to open only in the direction of a ventricle. If blood pushes against the valve in the direction of an atrium, the valve is forced closed. No blood passes through! Each atrium and ventricle contracts and forces blood out of the heart and through the body. Then they relax and fill with blood.

The heartbeat has two sounds--"lub" and "dub." The "lub" sound is the ventricles contracting and the valves closing. When the ventricles relax, a "dub" sound is heard. The dub sound is produced by the closing of the valves at the exits from the heart.

To stay alive, your heart must pump constantly. Pumping is produced by alternate contractions and relaxations of each atrium and ventricle. A heart contracts more than three billion times during a normal lifetime! The human heart beats between 60 and 80 times per minute. This rate is slightly faster than one beat per second. In one minute, it pumps about 5 liters.

How Blood Vessels Work to Carry Blood

Arteries (AR ter eez), veins (VAYnz) and capillaries (KAP uh ler eez) are three kinds of blood vessels. Arteries carry blood away from the heart. Veins carry blood to the heart. Capillaries are the tiny blood vessels that connect arteries and veins.

Arteries. Blood is forced into the arteries each time the ventricle contracts. Blood in the arteries is under great pressure and moves more rapidly. You can feel a movement in your wrist every time the arteries stretch and fill with blood. The stretching of the artery wall is called a pulse. Each beat causes a pulse in an artery. The heart and artery keep perfect time. Your pulse has the same rhythm as your heartbeat.

The walls of arteries assist in pumping blood. An artery has thick walls. Blood is pumped into them. The walls expand and contract. An artery exerts a pumping force when it contracts. Thus, the large arteries help move blood through the body.

Veins. Veins carry blood to the heart. The walls of veins are thin and contain less muscle tissue. Veins have cuplike valves. This prevents the backflow of blood. These valves keep the blood flowing toward the heart.

Veins carry dark red blood low in oxygen. The veins visible in your skin do not appear dark ed. They are blue. Pigment in your skin and veins makes the vessels appear blue.

Capillaries. Capillaries are the tiny blood vessels that connect arteries and veins. They are visible only with a microscope. Capillaries have a diameter about equal to the size of a red blood cell. Red blood cells pass through the smallest capillaries in single file. Capillaries are the most numerous and smallest blood vessels.

Materials go back and forth between the capillaries and the tissues. Diffusion of food and oxygen from blood to the tissues occurs in the capillaries. Waste materials move in the opposite direction. Wastes enter the capillaries. Wastes are carried away for excretion.

Capillaries help control the amount of heat lost from the body. During exercise, capillaries in the skin expand bringing more warm blood to the body surface. The body is cooled as heat from the blood escapes to the environment. When air temperature is low, capillaries in the skin contract. This reduces the flow of blood to the skin and decreases heat loss from the body.

How Blood Circulates Through the Body

Blood circulates through two main pathways: pulmonary (PUHL muh ner ee) circulation, and systemic (sis TEM ik) circulation. Systemic circulation includes coronary (KOR uh ner ee) circulation, renal (REEN uhl) circulation, and portal (PORT uhl) circulation. All of these pathways make up the circulatory (SUHR kyuh luh tor ee) system.

The flow of blood through the heart and to and from the lungs is the pulmonary circulation. Blood enters the right atrium from the large veins. Contraction of the right ventricle forces blood from the heart into the pulmonary artery. Blood travels through the pulmonary artery to the lungs and into the lung capillaries. There it picks up oxygen and loses carbon dioxide. The oxygen-rich blood travels through the pulmonary vein back to the left atrium of the heart.

Blood is pumped from the left atrium of the heart to the left ventricle. A valve prevents the blood from going back into the atrium. Blood is pumped out of the left ventricle into the aorta (ay ORT uh). The aorta is the largest artery in the body. The left ventricle exerts more force than any other chamber.

Systemic circulation includes blood vessels that go to and from the heart. Systemic circulation supplies most of the body tissues with nutrients and oxygen.

Coronary circulation is the movement of blood through the heart tissues. Two main coronary arteries leave the aorta. They curve downward on each side of the heart. Smaller arteries then branch off and enter the heart tissue. These arteries lead to capillaries which carry blood to the tissues. Coronary capillaries join to form coronary veins. Coronary veins empty the blood into the right atrium.

Renal circulation is part of the systemic circulation. The renal circulation includes vessels to and from the kidneys. A separate renal artery branches from the aorta to each kidney. Capillaries then weave their way through the kidneys. Kidneys remove mineral waste, organic waste, and excess water from the blood. These capillaries join to form the renal veins. Renal veins return blood to the major veins.

Portal circulation transports blood from the digestive tract and related organs to the systemic circulation. It includes a network of veins that combire to form a single, large portal vein. The portal system drains blood from the small intestines, liver, and pancreas.

As you can see, the heart and blood vessels are specially made for circulating human blood to every part of the body.

(Microstructure Version)

HUMAN BLOOD CIRCULATION

How the Heart Pumps Blood

The heart is the part of the circulatory system that pumps blood throughout the body. The heart is located in the center of the chest behind the breastbone and between the lungs. The human heart is a cone-shaped, muscular organ about the size of a large fist.

A human heart contains four chambers--right atrium (AY tree uhm), left atrium, right ventricle (VEN trih kuhl), and left ventricle. (Right and left refer to the body's right and left sides.) A wall separates the chambers on the right from the chambers on the left. A valve separates each atrium from the ventricle below it.

Here is how the each side of the heart pumps blood. First, blood from the body enters an atrium. Then, contraction of an atrium forces blood into the ventricle below it. The valve separating an atrium from a ventricle is very important because it prevents the blood from returning to an atrium. How? Its construction allows the valve to open only in the direction of a ventricle. If blood pushes against the valve in the direction of an atrium, the valve is forced closed. No blood passes through! Finally, the ventricle contracts and forces blood out of the heart and through the body. After blood has left a chamber, the walls of the chamber relax and the chamber fills with blood again.

The heartbeat has two sounds coming from the movements of the valves closing and the ventricles contracting--"lub" and "dub." The "lub" sound is the ventricles contracting and the valves closing between each atrium and ventricle. When the ventricles relax, a "dub" sound is heard. The dub sound is produced by the closing of the valves at the exits from the heart.

In order for you to stay alive, your heart must pump constantly. Pumping is produced by alternate contractions and relaxations of each atrium and ventricle. Just think, a heart contracts more than three billion times during a normal lifetime! The human heart beats at a rate between 60 and 80 times per minute. This rate is slightly faster than one beat per second. In one minute, the heart pumps about 5 liters of blood.

How Blood Vessels Work to Carry Blood

Arteries (AR ter eez), veins, (VAYnz) and capillaries (KAP uh ler eez) are three kinds of blood vessels. Arteries carry blood away from the heart. In contrast, veins carry blood to the heart. Capillaries are the tiny blood vessels that connect arteries to veins.

Arteries. Blood is forced into the arteries each time the ventricles contract. Blood in the arteries is under much greater pressure than blood in the veins. Therefore, blood moves more rapidly through the arteries. You can feel a movement in your wrist every time the arteries stretch and fill with blood. The stretching of the artery wall under pressure is called a pulse. Each beat of the heart causes a pulse in an artery. Together, the heart and artery keep perfect time. Thus, your pulse has the same rhythm as your heartbeat.

The walls of arteries also assist in pumping blood. An artery has a thick wall. The walls expand and contract as blood is pumped into them. An artery exerts a pumping force when it contracts. By pumping, the large arteries help move blood through the body.

Veins. Veins carry blood back to the heart. The walls of veins are thin and contain less muscle tissue than arteries. Veins have cuplike valves which prevent the backflow of blood. These valves keep the blood flowing toward the heart.

Veins carry dark red blood that is low in oxygen. However, the veins visible in your skin do not appear dark red. They are blue. Pigment in your skin and veins makes the vessels appear blue.

Capillaries. Capillaries are the tiny blood vessels that connect arteries to veins. They are visible only with a microscope. Capillaries have a diameter about equal to the size of a red blood cell. Therefore, red blood cells pass through the smallest capillaries in single file. Capillaries are the most numerous of the blood vessels.

Materials go back and forth between the capillaries and the tissues through which they pass. Diffusion of food and oxygen from the blood to the tissues occurs in the capillaries. Waste materials move out of the tissues in the opposite direction. In other words, wastes enter the capillaries and are carried away for excretion.

In addition to transporting needed materials, capillaries also help control the amount of heat lost from the body. During exercise, capillaries in the skin expand bringing more warm blood to the body surface. The body is cooled as heat from the blood escapes to the environment. In contrast, when air temperature is low, capillaries in the skin contract. This contraction of capillaries reduces the flow of blood to the skin, thus decreasing heat loss from the body.

How Blood Circulates Through the Body

Blood circulates in the body through two main pathways: pulmonary (PUHL muh ner ee) circulation, and systemic (sis TEM ik) circulation. Systemic circulation includes coronary (KOR uh ner ee) circulation, renal (REEN uhl) circulation, and portal (PORT uhl) circulation. All of these pathways make up the **circulatory** (SUHR kyuh luh tor ee) system.

One major pathway, pulmonary circulation, is the flow of blood through the heart and to and from the lungs. Blood enters the right atrium from the large veins that return blood to the heart and is pumped into the right ventricle. Contraction of the right ventricle forces blood from the heart into the pulmonary artery. Blood travels through the pulmonary artery to the lungs and into the lung capillaries. There it picks up oxygen and loses carbon dioxide. The oxygen-rich blood then travels through the pulmonary vein back to the left atrium of the heart.

Blood is pumped from the left atrium of the heart to the left ventricle. A valve prevents the blood from going back into the atrium. Blood is pumped out of the left ventricle into the aorta (ay ORT uh). The aorta is the largest artery in the body. When the left ventricle contracts, it exerts more force than any other heart chamber.

Systemic circulation, the other major pathway of blood in the body includes all other blood vessels that go to and from the heart. Systemic circulation supplies most of the body tissues with nutrients and oxygen.

Coronary circulation, a part of the systemic circulation, is the movement of blood through the heart tissues. Two main coronary arteries leave the aorta. They curve downward on each side of the heart. From these coronary arteries, smaller arteries then branch off and enter the heart tissue. These arteries lead to capillaries which carry blood to the tissues of the heart. Then coronary capillaries join to form coronary veins. Coronary veins empty the blood into the right atrium of the heart.

Renal circulation is also part of the systemic circulation. The renal circulation includes blood vessels to and from the kidneys. A separate renal artery branches from the aorta to each kidney. From the renal arteries, capillaries then weave their way through the kidneys. While blood flows through these capillaries, mineral waste, organic waste, and excess water are removed from the blood. After wastes are removed, the capillaries join to form the renal veins. Renal veins return blood to the major veins leading back to the heart.

Portal circulation transports blood from the digestive tract and related organs to the systemic circulation through a network of veins that combine to form a single, large portal vein. The portal system drains blood from the small intestines, liver, and pancreas.

As you can see, the heart and blood vessels are specially made for circulating human blood to every part of the body.

(Elaborated Version)

HUMAN BLOOD CIRCULATION

How the Heart Pumps Blood

The heart is the part of the circulatory system that pumps blood throughout the body. The heart is located in the center of the chest behind the breastbone and between the lungs. The human heart is suited for pumping because it is a hollow, cone-shaped, muscular organ about the size of a large fist. Being hollow, the heart can easily fill up with blood. Once filled, the heart muscle provides the power necessary for pumping the blood through the body.

A human heart contains four hollow chambers made for receiving and sending blood. The right atrium (AY tree uhm), and right ventricle (VEN trih kuhl) receive and send blood to the lungs, while the left atrium, and left ventricle receive and send blood to the rest of the body. (Note that right and left refer to your body's right-hand and left-hand sides). The right and left sides of the heart are separated by a wall of muscle. This wall keeps blood going to the lungs separate from the blood going to the body.

Here is how each side of the heart pumps blood. First, blood coming into the heart enters an atrium. When an atrium contracts, blood is forced into the ventricle below it. The valve separating an atrium from a ventricle is very important because it prevents the blood from returning to an atrium. How? Its construction allows the valve to open only in the direction of a ventricle. If blood pushes against the valve in the direction of an atrium, the valve is forced closed. No blood passes through! Finally, the ventricle contracts and forces blood out of the heart and through the body. After blood has left a chamber, the walls of the chamber relax and the chamber fills with blood again.

The heartbeat has two sounds coming from the movements of the valves closing and the ventricles contracting--"lub" and "dub." The "lub" sound is the ventricles contracting and the valves closing between each atrium and ventricle. When the ventricles relax, a "dub" sound is heard. The dub sound is produced by the closing of the valves at the exits from the heart, that is, valves between the ventricles and blood vessels going to the body.

In order for you to stay alive, your heart must pump constantly. Pumping is produced by alternate contractions and relaxations of each atrium and ventricle. Just think, a heart contracts more than three billion times during a normal lifetime! The human heart beats at a rate between 60 and 80 times per minute. This rate is slightly faster than one beat per second. In one minute, it pumps about 5 liters of blood, which is most of the blood in your body.

How Blood Vessels Work to Carry Blood

The heart pumps blood through a continuous network of blood vessels (tubes) that circulate the blood throughout the body. Arteries (AR ter eez), veins (VAYnz) and capillaries (KAP uh ler eez) are three kinds of blood vessels. Arteries carry blood away from the heart. In contrast, veins carry blood to the heart. Capillaries are the tiny blood vessels connecting arteries to veins. Each kind of blood vessel is specially suited for its job.

Arteries. Blood is forced into the arteries each time the ventricles contract. Because of the force of the pumping, the blood moves rapidly through the arteries. You can feel this movement in your wrist every time the arteries stretch and fill with blood. The stretching of the artery wall under pressure creates a pulse. Each beat of the heart causes a pulse in an artery. Together, the heart and artery keep perfect time. Thus, your pulse has the same rhythm as your heartbeat.

The walls of arteries are thick and muscular. Why? First, thicker walls are needed because arteries are stretched with each pulse of blood. Thinner walls could break. Second, arteries assist in pumping blood. When the walls expand as blood is pumped into them, the artery wall exerts a pumping force by contracting its muscular walls. This additional pumping by the large arteries helps keep blood circulating through the body.

Veins. Veins carry blood back to the heart. Because this returning flow of blood is farther from the pumping of the heart, it is under lower pressure than blood in the arteries. Therefore, the walls of the veins can be thinner because less muscle tissue is needed than in arteries. Thick walls are not needed; but veins do need some way to keep blood flowing upward to the heart. Imagine blood travelling from your foot back to your heart. What prevents the blood from flowing downwards instead of upwards? Veins have cuplike valves which prevent the backflow of blood. The "cups" catch the blood in between pulses in the blood pressure. Such one-way valves keep the blood flowing up toward the heart.

Because blood in veins is on its way back to the heart and lungs, the blood is low in oxygen and is now a dark red color. However, veins visible in your skin do not appear dark red. Look at your wrist. Veins appear as "blue" lines under your skin. Actually they are dark red. It is the pigment in your skin and veins that makes the veins appear to be blue.

Capillaries. Capillaries are the tiny blood vessels that conn arteries to veins. The arteries continually branch off becoming smaller and smaller. Where the artery walls are only one cell thick, they become capillaries. Capillaries are visible only with a microscope. In fact. ten capillaries placed side by side are no wider than a hair. They have a diameter about equal to the size of a red blood cell. Red blood cells pass through the smallest capillaries in single file. Capillaries join together to form veins. Veins carry blood back to the heart.

Capillaries are so numerous that every cell in the body is next to or very near a capillary. When blood passes through capillaries, diffusion of oxygen and nutrients occurs through the thin capillary walls. As nutrients and oxygen move into the body tissues, waste materials and carbon dioxide move out in the opposite direction. Wastes and carbon dioxide from the tissues also enter the capillaries by diffusion. Waste materials are carried away in veins for excretion from the body.

In addition to transporting needed materials, capillaries also help control the amount of heat lost from the body. During exercise, capillaries in the skin expand bringing more warm blood to the body surface. The body is cooled as heat from the blood escapes to the environment. When air temperature is low, capillaries in the skin contract. This reduces the flow of blood to the skin and decreases heat loss from the body. If body temperature were not controlled, the body could not function properly.

How Blood Circulates Through the Body

Blood circulates in the body through two main pathways: pulmonary (PUHL muh ner ee) circulation, and systemic (sis TEM ik) circulation. Systemic circulation includes coronary (KOR uh ner ee) circulation, renal (REEN uhl) circulation, and portal (PORT uhl) circulation. All of these pathways make up the circulatory (SUHR kyuh luh tor ee) system.

One major pathway, pulmonary circulation, is the flow of blood through the heart and to and from the lungs. Blood enters the right atrium from the large veins that return blood to the heart. Blood returning to the right side of the heart is low in oxygen so it must be pumped to the lungs in order to obtain more oxygen. To get blood to the lungs, the right atrium contracts and a fraction of a second later the right ventricle contracts, thus forcing blood from the heart into the pulmonary artery. Blood travels through the pulmonary artery to the lungs and into the lung capillaries. There the blood picks up oxygen and gives off carbon dioxide. The oxygen-rich blood then travels through the pulmonary vein back to the left atrium of the heart.

Blood is pumped from the left atrium of the heart to the left ventricle. A valve prevents the blood from going back into the atrium when the left ventricle contracts. The left ventricle exerts more pumping force than any other heart chamber. Blood pumped out of the left ventricle enters the aorta (ay ORT uh). The aorta, which supplies blood to all arteries in the body except those going to the lungs, is the largest artery in the body.

Systemic circulation, the other major pathway, includes all blood vessels that go to and from the heart anywhere in the body (head, arms legs, and so on) except to and from the lungs. Systemic circulation supplies the body with nutrients and oxygen.

Coronary circulation, a part of the systemic circulation, is the movement of blood through the heart tissues. Two main coronary arteries leave the aorta. They curve downward on each side of the heart. From these coronary arteries, smaller arteries branch off and enter the heart tissues. These smaller arteries lead to capillaries which carry blood full of oxygen and nutrients to the tissues of the heart. Then coronary capillaries join to form coronary veins. Coronary veins empty the blood into the right atrium of the heart where it will be returned to the lungs before going to body tissues again.

Renal circulation is also part of the systemic circulation. The renal circulation includes blood vessels to and from the kidneys. A separate renal artery branches from the aorta to each kidney. From the renal arteries, capillaries weave their way through the kidneys. While blood flows through these capillaries, mineral waste, organic waste, and excess water picked up from body tissues are removed from the blood. After wastes are removed, the capillaries join to form renal veins. Renal veins then return the blood to the major veins leading back to the heart.

The pulmonary circulation adds oxygen to the blood, but it is the portal circulation that adds nutrients. Diffusion of nutrients into the blood occurs as the blood flows by the walls of the small intestines. The portal circulation then carries the nutrient-rich blood to the liver. As the blood flows through the tissues in the liver, the liver changes the nutrients into substances useful to the body and stores other nutrients for future use. From the liver, the nutrient-rich blood returns to the heart to be pumped to the rest of the body.

As you can see, the heart and blood vessels are specially made for circulating human blood--to take oxygen and nutrients to cells and to remove wastes from cells--all of which is necessary for life!