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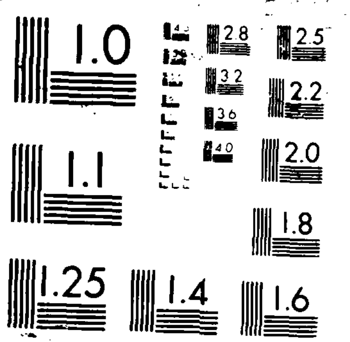
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ANSWERING QUESTIONS FROM OCEANOGRAPHY TEXTS: LEARNER TASK AND TEXT CHARACTERISTICS

Susan R. Goldman and Richard P. Durán

Cognitive Science Technical Report #8718
September, 1987

This research was sponsored by the Personnel and Training Research Programs, Psychological Sciences Division, Office of Naval Research, under Contract No. N00014-85-K-0562, Contract Authority Identification Number, NR442c015.

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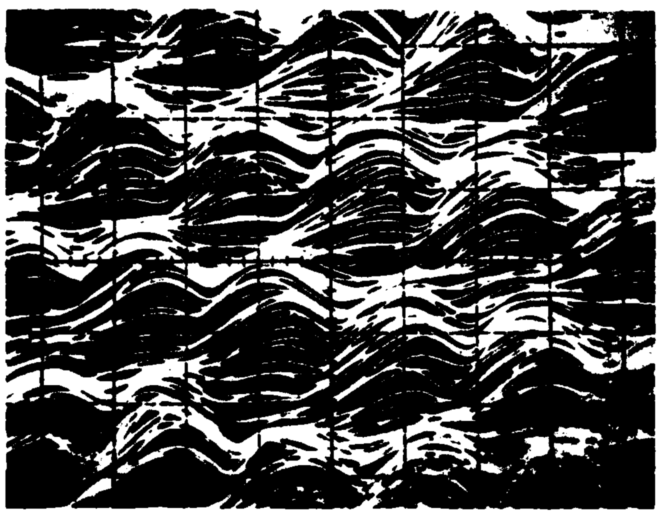

TECHNICAL REPORT

UNIVERSITY OF CALIFORNIA, SANTA BARBARA SANTA BARBARA, CALIFORNIA 93106

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE

A190 122

REPORT DOCUMENTATION PAGE

Form Approved
OMB No 0704-0188

1a REPORT SECURITY CLASSIFICATION: Unclassified	1b RESTRICTIVE MARKINGS
2a SECURITY CLASSIFICATION AUTHORITY	3 DISTRIBUTION / AVAILABILITY OF REPORT: Approved for public release; distribution unlimited.
2b DECLASSIFICATION / DOWNGRADING SCHEDULE	
4 PERFORMING ORGANIZATION REPORT NUMBER(S): Cognitive Science Technical Report #8718	5 MONITORING ORGANIZATION REPORT NUMBER(S)
6a NAME OF PERFORMING ORGANIZATION: University of California; 6b OFFICE SYMBOL (If applicable)	7a NAME OF MONITORING ORGANIZATION: Personnel and Training Research Programs Office of Naval Research (Code 1142PT)
6c ADDRESS (City, State, and ZIP Code): Santa Barbara, CA 93106	7b ADDRESS (City, State, and ZIP Code): 800 North Quincy Street Arlington, VA 22217-5000
8a NAME OF FUNDING / SPONSORING ORGANIZATION; 8b OFFICE SYMBOL (If applicable)	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER: N00014-85-K0562
8c ADDRESS (City, State, and ZIP Code)	10 SOURCE OF FUNDING NUMBERS: PROGRAM ELEMENT NO 61153N; PROJECT NO RR04206; TASK NO RR4206-DC; WORK UNIT ACCESSION NO NR442c015

11 TITLE (Include Security Classification)
Answering questions from oceanography texts: Learner, task and text characteristics

12 PERSONAL AUTHOR(S)
Susan R. Goldman, Richard P. Durán

13a TYPE OF REPORT	13b TIME COVERED	14 DATE OF REPORT (Year, Month, Day)	15 PAGE COUNT
Technical	FROM 1985 TO 1988	1987, September, 15	66

16 SUPPLEMENTARY NOTATION

17 COSATI CODES			18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Learning from text
05	10		English-as-a-second-language (ESL)
			Question answering

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

Seven college students enrolled in a college-level introductory oceanography course read and answered questions on two selections drawn from their textbook in the course. Using verbal protocol procedures, three nonnative English speakers and four native English speakers described what they were doing to answer the questions. Students also varied in level of expertise based on their backgrounds in related science courses. The questions varied in terms of their relationship to the text and the type of processing required to answer them. A model of question answering from academic texts is proposed and this model guided protocol analysis. Solution strategies were abstracted from the protocols and indicated predicted effects of question type on difficulty and on solution strategies Differences between individuals were related to domain expertise and to language background.

20 DISTRIBUTION / AVAILABILITY OF ABSTRACT: ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21 ABSTRACT SECURITY CLASSIFICATION: Unclassified
22a NAME OF RESPONSIBLE INDIVIDUAL: Dr. Susan Chipman	22b TELEPHONE (Include Area Code): (202)696-4318; 22c OFFICE SYMBOL: ONR 1142PT

DD Form 1473, JUN 86 — Previous editions are obsolete — SECURITY CLASSIFICATION OF THIS PAGE

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University of California, Santa Barbara

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Abstract

Seven college students enrolled in a college-level introductory oceanography course read and answered questions on two selections drawn from their textbook in the course. Using verbal protocol procedures, three nonnative English speakers and four native English speakers described what they were doing to answer the questions. Students also varied in level of expertise based on their backgrounds in related science courses. The questions varied in terms of their relationship to the text and the type of processing required to answer them. A model of question answering from academic texts is proposed and this model guided protocol analysis. Solution strategies were abstracted from the protocols and indicated predicted effects of question type on difficulty and on solution strategies. Differences between individuals were related to domain expertise and to language background.

This report is an expanded version of the paper "Text and Learner Characteristics that Affect Learning from Academic Texts", presented at the meetings of the Psychonomic Society, New Orleans, Louisiana, November, 1986. This research was sponsored by the Personnel and Training Research Programs, Psychological Sciences Division, Office of Naval Research, under Contract No. N00014-85-K-0562, Contract Authority Identification Number, NR442c015.

It has become almost commonplace to assert that comprehension is an interactive process in which the learner, the task and the text all play a role (e.g. Brown, Campione & Day, 1981). Over the past year and a half we have been conducting research that attempts to understand and detail this obvious but elusive interaction between learner, task and text characteristics. The purpose of the present report is to describe the question-answering task we have been using to explore these interactions. We have formulated a model of the question-answering process that has been used to guide the coding and interpretation of verbal protocols collected from students who vary along several dimensions known to have important effects on learning. Two learner characteristics we have been concerned with are: language proficiency of nonnative English speakers and prior knowledge. We are focusing on language proficiency as it relates specifically to the language used in academic texts. What proficiencies are needed when attempting to learn new information from a text? What, if any, problems are unique to nonnative English speakers confronted with this task? Prior knowledge is of interest to us particularly as it interacts with language proficiency. High versus low knowledge effects on comprehension and reasoning have been demonstrated by a number of researchers, (e.g. Chiesi, Spilich, & Voss, 1979; Dee Lucas & Larkin, 1986; Spilich, Vesonder, Chiesi, & Voss, 1979). Thus, a general issue with which we are concerned is the interaction of language proficiency and domain-specific knowledge.

The text characteristics upon which we have been focusing relate to local and global language structures that are used to convey meaning between and among individual units of information. Such devices impact text cohesion and the learner's ability to construct a coherent representation of the text. Examples of local language structures are conjunctions, conditionals, performatives, and quantification terms and phrases (see for further discussion Celce-Murcia &

Larson-Freeman 1983). Examples of global text structures are compare/contrast, thesis/evidence, procedural and cause-effect. These global structures are typically signalled by rhetorical devices at the paragraph level (e. g. Brewer, 1980; Meyer, Brandt, & Bluth, 1980).

Finally, we have been looking at a number of task characteristics that arise from a consideration of comprehension skill hierarchies (Rosenshine, 1980) and envisionment levels (Fillmore, 1983; Kay, in press; Langer, in press). Comprehension skills hierarchies imply an increasingly more sophisticated understanding as one moves from "literal" comprehension of the text, to making simple inferences from the text, to engaging in more complex inferential reasoning based on the information in the text. Comprehension tasks can be thought of as varying along a continuum reflecting the degree to which the task can be successfully completed with "only" the text as compared to requiring material and knowledge external to the text (see for discussion Goldman, 1985). Variation in the amount of text dependency is also reflected in the envisionment levels of reasoning proposed by Fillmore (1983). Envisionment levels refer to variations in individuals' understanding of the world described in a text. These levels range from the most basic, "Understanding independent statements in a text", to the most complex, "Embellishing the text world in light of existing knowledge and in terms of possible extensions and underlying generalities". The more basic levels are more text dependent, literal understandings.

With respect to the interaction of learner, text and task characteristics we have examined the comprehension and reasoning performance of non-native English Speakers (ESL) engaged in question answering, recall, outlining and rewriting tasks with oceanography texts that they have been studying in connection with the introductory level course in this domain. The four tasks demand varying levels of comprehension and reasoning and in doing the tasks students may exhibit different degrees of dependency on the text. We employed a think-aloud protocol methodology to examine the strategies learners employed, given their levels of expertise in the domain, their English language proficiency and the requirements of the specific tasks. Despite the potential difficulty of talking and working with English text concurrently, we note that think-aloud procedures have been efficaciously used with ESL students in previous work on reading and reading strategies (e.g. Benedetto, 1986; Block, 1986 a,b). The present report focuses soley on the performance characteristics of the question answering task. By design, the questions varied with respect to the degree of text - internal versus text - external reasoning (Goldman, 1985) required for correct solution. This dimension refers to the degree to which the text provides all of the information needed to answer the question, as compared to questions that require inferences that go beyond the text to be answered. In addition to the variation in the task demands for the questions, an additional level of variation was introduced by presenting learners with a text section that had already been studied in class (from Chapter 2) and one that had not been studied (from Chapter 12) at the time we tested them. Thus, in answering questions on the "old" material (Chapter 2) each student should have had more knowledge than when answering the questions on the "new" material.

Method

Materials.

Two sections from the text used in an introductory oceanography course, Ocean Science (Stowe, 1983) were selected. The text sections were approximately 1500 words in length and featured a representative sampling of the type of concepts students in the course have to deal with. These include definitions of terms, properties of geophysical phenomena, and mathematical relations and physical laws. The first section was from Chapter 2 and covered methods for studying the earth's interior. It included one formula, one table, and six figures illustrating various geophysical principles, including the effects of subsurface mass distributions on gravitational force, Snell's law, and properties of sound waves. The text was parsed into 157 predicate propositions (Kintsch, 1974) or idea units (Chafe, 1985). These were characterized with respect to intersentential cohesion and types of logical relations. The second section was from Chapter 12 and described the relationship between the ocean and climate and included evaporation, the hydrologic cycle and thermal flow. There were two tables and one figure. This section contained 154 predicate propositions and employed intersentential cohesive relations that were roughly equivalent to those found in Chapter 2. Comprehension questions were drawn from the study guide for the class and in three cases were developed by the authors. Questions varied with respect to the envisionment or comprehension level necessary to arrive at a successful answer. (Appendix A contains reproductions of the text selections, the questions and their answers.)

Subjects.

Seven students participated in the question-answering protocol study. Six were enrolled in the introductory oceanography course and the seventh (HS) was the teaching assistant for the course. Students completed a background questionnaire dealing with academic information, language skills and study habits. Table 1 provides a summary of the most pertinent information from this questionnaire. The teaching assistant and three of the students were native English speakers (MR, LH, and DW). The other three students (GL, II, and EH) were from three different non-English language backgrounds but were relatively proficient in English. GL rated his English language skills "extremely good"; II and EH each rated their skills "good". The four native English speakers rated their own English language skills "extremely good." The language of instruction during high school had been English for all the students. EH had had the least exposure to English, having entered the United States six years ago, at which time she had her first contacts with English. II and GL were first exposed to English at the age of 4 years. Of the non-native English speakers, only EH reported using her native language daily. GL and II reported that they used their native languages to read newspaper or magazine material but rarely. [1]

All students' high school backgrounds included courses in chemistry and/or biology. MR and DW were college seniors, GL a junior, LH a sophomore and EH and II were freshmen at the time of the study and experience with college-level science courses varied. MR had an extensive background in physics and HS in oceanography. DW and GL had taken astronomy. The other three students had no college-level science courses but II had had physics in high school. The majors of the seven students varied and included physics (MR), business/economics (EH, II), communications (LH) and sociology (DW). Table 1 also describes the self-ratings of English language skills related to academic performance. These ratings suggest that the native and nonnative English speakers differ primarily in terms of their command of science vocabulary. Ratings on learning from English lectures were in "good" and "extremely good" for all students. Learning from English texts skills were rated higher ("extremely good") by the native English speakers as compared to the nonnative English speakers ("good").

Procedure.

Students were recruited through the introductory oceanography class. They volunteered to participate in four, 2-hour sessions and were paid $5 per hour for their participation at the conclusion of the fourth session. Students were told that we were interested in how they went about answering questions on oceanography material and that we wanted them to think aloud as they worked on several questions that we would give them. Students completed the background questionnaire first. Then the think-aloud method was described and modeled, following procedures outlined by Ericsson and Simon (1984). Subjects were encouraged to talk aloud as they were working each question and were told that they would be prompted to verbalize if there were periods of silence. The technique was illustrated with a mental, multicolumn multiplication problem. After the subject had completed the think-aloud solution, instructions for a retrospective talk-aloud protocol were given: subjects were instructed to report what they had been thinking from the time they heard the question until the time they gave the answer. Two more practice exercises were given ("How many windows in your parents' house?" and "Name 20 animals") and subjects provided both think aloud and retrospective protocols. Note that although retrospective training was given, the procedure enacted only requested a retrospective when the think-aloud protocol was very brief and noninformative. This was done because using both became too repetitious and arduous for the subjects.

During the first session, each student was given the "old" selection (the section from Chapter 2) and six questions, one at a time. After the student had answered the questions, the experimenter asked subjects to go back over the text selection and indicate what part(s) were particularly difficult to negotiate.

Approximately one week later, each subject returned for the second session on Chapter 2. They were asked to orally recall what they remembered from the selection read during the first session. Then they were given the next two subheaded sections of Chapter 2 to read and outline, employing the think-aloud method during the outlining.

Approximately three to four weeks later, each subject returned for the third session. During this session, the first section from Chapter 12 was presented and subjects answered six questions and performed a difficulty analysis. Returning one week later, oral recall of this section and reading and outlining of the continuation of this section were completed. All sessions were audiotaped and later transcribed. This paper deals only with the question answering task.

Analysis of the Question-answering Protocols

Process model.

Protocol analysis was guided by the question answering model shown in Table 2. The model was developed to specifically deal with questions on academic text material. The model indicates four major processing events and the goals associated with each one. In addition, metacognitive processing events are shown as optional. Monitoring can apply to any of the processing events and/or to learners' general thoughts about their performance, the task, the text, etc.

Each major processing event may be further "unpacked" or expanded, into its constituent processes, goals and procedures. The first processing event, question encoding, has two primary goals. The expansion of these goals is shown in Table 3. The first goal is to determine the type of question. Questions vary in terms of the level of envisionment demanded and the level is, in part, dependent on the relationship between the text and the question. Processing difficulty and the amount of reasoning required for successful question answering varies with such question requirements. For example a question that requires an explanation that must be constructed from the material given in the text will require more processing resources than a question whose answer can be found verbatim in the text, regardless of whether it is an explanation, comparison, or simple "fact." Two example questions that were used in the present study illustrate the nature of the differences in task demands among the question set. Question 12,3 has five parts that vary in task demands:

> a) Suppose air at 25° C is saturated (100% relative humidity). What fraction of the air is water? (b) What would be the answer if the temperature were 35°? (c) 15°? (d) 5°? (e) Does the answer change by roughly a factor of 2 for every 10°?

The answers to parts *a* and *e* can be found verbatim in the text; the answers to *c* and *d* can be read directly from a table given in the text. The answer to *b* must be computed but it can be computed in two ways. The individual can either apply the rule referred to in part *e* of the question or can interpolate from the series given in the table in the text. Another example, Question 2,6 illustrates an explanation question where vocabulary is a critical issue: "Briefly explain how 'echoes' can be used to measure the depths of discontinuities in the earth's internal structure." To locate relevant portions of the text or to access the appropriate concept in memory, the learner must understand the equivalence between the phrase in the question, *depths of discontinuities*, and the phrase used in the text *interfaces between materials.* Furthermore, there are several sections of the text that are relevant and two factors that need to be discussed, time and speed. Time is discussed in a three sentence section that is separated by nine sentences from the section that deals explicitly with the time and speed relationship. To give the complete answer, the learner must integrate across sections of text and extract the pertinent relationship. The text does indicate that the learner ought to read on for the complete answer:

> "The first item (time) could be read from your seismograph, but there is no direct way to know the speed of seismic waves deep within the earth. Fortunately, this information may be inferred from data, due to the other important property of waves.
> This second property is...." (speed is mentioned again 3 sentences later.)

However, not all learners were sensitive to this cue when they answered this question.

To accomplish the goal of determining what the question requires, the primary means, as shown in Table 3, is to rely on the language of the question. Analysis of the language draws on prior experiences with other academic texts and a sensitivity to the semantics of various question words, such as how many, what and why. To the knowledgeable individual, these questions words provide cues to the appropriate form of the answer. A "how many" question ought to indicate the need for a specific quantity, a "why" for a causal or logical explanation of the phenomenon mentioned in the question. In addition, learners may use the task context and constraints to further define the nature of the answer. In an untimed situation, one can afford to be more discursive than in a time-limited one. Furthermore, the space provided for the answer often provides information to the learner; compare for example, fill-in-the-blank with a half page of blank space.

The second major goal of question encoding is to determine starting points for a search space. A primary means of doing this is to use technical terms and keywords concepts mentioned in the question as entry points to memory and/or the textbook. When the question uses words that match those used in the headings and subheadings of the text, learners are virtually assured of a reasonably well-defined search space in the text. Key term matching is also facilitated by the use of boldface or italics in the body of the text. In defining a search space in memory, the key terms in the question behave similarly but the success of a match will vary depending on learners' individual mental representations of the text information. Regardless of whether the learner is defining a search space in the text or in semantic memory, there is the possibility that the words in the question will be seductively appealing as cues, when in fact the question really requires original thinking or the application of presented material. Questions of this sort are not only at more complex envisionment levels but also provide "false" signals to the learner, creating the impression that the answer is "in the book".

As indicated above, an important outcome of question encoding is the definition of the search space and type of answer required. Search proceeds either in memory or in an external source such as a textbook, notes or supplementary reference material. The goals differ somewhat for memory and text searches, as shown in Table 2. The goals for memory search distinguish between two outcomes. In the first goal, the answer is found in memory and no external search is undertaken. For this to occur, we assume that decision criteria operate and that any memory search is monitored and its progress evaluated. We further assume the existence of a threshold or criterion against which candidate answers are tested. When an answer exceeds threshold it is output by the learner. Memory search that does not produce an answer exceeding critical value for output will eventuate in two outcomes: (1) the learner will conclude that the answer is not known, or cannot be remembered; (2) the learner will conclude that external sources are needed to find the answer. Individual differences in learners govern the extensiveness of, and persistence in, memory searches. If memory search is abandoned for external source search, a second goal of the memory search is to determine alternate sources for the answer. Thus, a memory search may not produce the answer but may further define, and refine, subsequent search spaces. External source search can thus be facilitated by a memory search that does not yield the specific answer to the question. The memory search phase of the model is the one about which we will have the least to say based on the protocol data (see Reder, 1987, for a recent theoretical and empirical focus on question answering from memory).

Goals for external searches are similar to those for memory in that we assume the operation of decision, monitoring and evaluation processes during the course of the search. In searching a textbook, learners may have three major goals that are interdependent and interrelated, as outlined in Table 4. One goal is to delimit the search space by using the results of question encoding and memory search to constrain and guide textbook processing. This goal becomes increasingly important as the amount of potentially appropriate text material increases. It would be relatively unimportant when the student knows that the questions pertain to a section consisting of only a few pages of text.

A second goal, finding information relevant to the question,will be achieved with less effort if the search space can be appropriately limited but will be more difficult if the search space is incorrectly constrained. Given a section of text to search, the search may be global or guided, as shown in Table 4. Global searches commence with the learner having only a vaguely defined search space, e. g., "I'll look in the text for that. It must be there somewhere." Such searches are typically characterized by scanning or skimming of text and may be exhaustive or self-terminating. Monitoring, evaluation and decision processes are tuned to the occurrence of concepts, vocabulary, or other text material that "matches" the requirements of the question. When a match is encountered the learner's attention becomes focused on that section of text and more careful examination of the text replaces the skimming behavior. The search process, in effect, changes to a guided search. Guided search is, from the outset, targeted at a defined search space, a localized area of the text. Key words and topics mentioned in the question are used by the learner to explicitly identify and focus on specific sections of text, e. g., "This question is about gravity. That's section two. I'll look there."

Whether learners employ guided or global search strategies is, in part, related to the degree to which the search space has been delimited and the question appropriately encoded. Frequent monitoring of the utility of text searches is important for efficient and successful search behavior. In particular, as Table 4 indicates, when the question requires that text be paraphrased, summarized or be the input to some sort of reasoning and analysis process, evaluation of the pertinence of the specific text "facts" is essential to the learner's success. Failure of this process can lead to extended and unsuccessful text searches. The converse is true regarding false recognition of text information, that is, recognizing irrelevant information as relevant to the answer.

Once relevant information is located it must be meaningfully processed. The learner must extract the relevant information in a form that suits the task demands. Example means to accomplish this are listed in Table 4. For some questions, just recognizing the right material and reading it from the text is sufficient. For other types of questions, summarization may be called for and in still others, the learner may need to engage in extended reasoning and knowledge application processes.

DW's protocol for question 6 from chapter 12 that required the explanation of an everyday occurrence illustrates the interdependence and interrelatedness of the goals and processing events in the question encoding, memory search and text search components of the model. This particular question, "Explain why you feel cold when you get out of the shower", is directly answered in the text and the specific information is contained in one paragraph. However, references to the concept involved, "evaporation", occur in the three paragraphs preceding the answer and in the four paragraphs following the answer. DW's coded protocol is shown in Table 5. She first encoded the question by reading it and defining the topic as one of the major ones in that section of text, "latent heat". She then gave an answer from memory, "because of the evaporation process", but evaluated her answer as insufficient for the question. She proceeded to a text search, presumably to gather more information on evaporation and why the process works that way. She began reading in the appropriate section, B.2 Latent heat, but two paragraphs below the one containing the answer. She skipped up the page to the topic sentence of the paragraph containing the answer (B.2S15). She then stated an answer that paraphrased S15 in nontechnical terms, deleting the details of molecular movement and its relationship to evaporation and temperature. She evaluated this answer as missing something and adopted a global search strategy of skimming from the beginning of Chapter 12 until she got to the first two sentences of section B.1, which use the key term "evaporate." She read two sentences and then skimmed the remainder of section B.1, assumedly because the "evaporation" match didn't lead anywhere on the shower explanation. She then read the first six sentences under section B.2, and recognized this as the relevant material. She re-read part of it (S3 - S6) and then continued reading about perspiration and evaporation. "This is also why we perspire. (S7) The heat required to evaporate the water comes from our skins, cooling us off. (S8)" DW then proceeded to paraphrase the information she had just read. However, she got tangled up, reread S8 and then reverted to her original answer:

> Well, I guess I'll do it (answer) in sort of a round about way. First of all, the heat, the hot water of the shower. You get out of the shower, and the water, which is storing the heat on your body, is...You usually dry it off, and the evaporation ... Um ... Actually, that's not true 'cause if it's cold outside the evaporation is a slower process. "The heat required to evaporate the water comes from our skin." Well, I guess I'd say evaporation, and leave it at that.

DW started by defining the search space as information on latent heat; she then retrieved an answer from memory, evaporation. This answer guided her attempts to search the text for more information. However, DW failed to see the importance of continuing with the paragraph starting with S15; instead she engaged in a global text search that took her away from the relevant information. She never got back to this paragraph but attempted to conclude her answer to this question with a paraphrases of a less-relevant text section (B.2S7 & 8). However this section is the first section under her self-defined topic, "latent heat," that mentioned the key term in her answer, "evaporation." She monitored her understanding and the paraphrase as not terribly direct but instead of resuming a search process, she retreated back to the same answer she had originally retrieved from memory and the one that provided the impetus for the initial text search. We can only speculate on why she "gave up" at this point.

DW's protocol also illustrated the fourth component of the question answering model, as shown in Table 2: Construct and output an answer. Two goals involved here are to answer the question completely and match the type of answer to the type of question. Question 12,6 required an explanation and DW indicated to us that her initial answer did not really qualify as an explanation by her self-question "But what is it that causes that?" Another learner, GL, indicated his attempt to meet the goal of answering completely after giving a correct partial answer to question 2,6. He stated: "Ok. I'll read it again and to find out exactly what these are used for. I mean I know they're used to measure depth but I know they have other (uses)." Table 6 "unpacks" the two aforementioned goals of answering and indicates a third, optional goal of demonstrating that the information has been incorporated into the knowledge base. Several of the students repeatedly paraphrased text sections they had just read aloud. We interpret this behavior as their efforts to comply with this optional goal. Attention to this goal may be one of the distinguishing features of expert learners.

Finally, the question-answering model features optional processes that relate to the role of metacognitive behavior in the question answering process. At any time, and for any of the "processing events", confirmation, monitoring and evaluation may be invoked by the learner. The outcomes of such monitoring, in part, determine the sequencing and interplay between the various processing events. For example, after reading a lengthy section of the text, a number of students were observed to reread the question. There are several related explanations for why that particular sequence occurred: first, the learner might have monitored memory for the specifics of the question and determined that the trace was not sufficiently active; second, the juxtaposition of the text and the question might help in the determination of the appropriateness of the just-read text to the exact question. Reder (1987) has suggested a third possibility: rereading may increase the familiarity of the concepts and thus the likelihood of success for direct retrieval of the answer.

Solution strategies.

The question answering model leads to a number of solution strategies depending on the particular selection of processing events, the specific goals that learners seek to meet within each processing event, and the degree and type of involvement of monitoring processes. A typology of solution strategies is shown in Table 7. A strategy consists of question encoding, some type of search, some set of additional processing events (including the empty set) and output of the answer.

Four types of search are specified, each of which can be accompanied by any of four "additional" processing events: question analysis, reasoning/inference, process monitoring or product monitoring. Types A - D differ in terms of the types(s) of searches that are undertaken and the outcome(s) of the search. Search Types A, B and C involve searches for which a successful outcome is possible, i.e. the correct answer can be "located" in memory (A), in the text (B) or by employing a combination of text and memory searches (C). In contrast, Type D represents a situation where the information is not in the text or could not have been stored in memory unless the learner had solved the problem previously. Type D searches lead to the recognition of the need to use given information, either by applying some rule or formula given in the text or by using the information in a novel problem solving context.

Each search type may be augmented by the occurrence of one or more of the four additional processing events. Question analysis refers to rereading or analyzing the nature of the question. Reasoning and inference refer to efforts to logically manipulate given or remembered information. Process and product monitoring refer to metacognitive behavior directed at the progress of any of the processing events (process monitoring) or at results of search and retrieval processes (product monitoring). The latter include reality-testing and checking behaviors directed at answers or candidate answers. Process monitoring includes self-questioning aimed at the text, the question or the learner's own internal state during the problem solving process. These are often evaluations of the relevance of specific portions of text, of whether or not a particular concept sounds familiar, or of whether a new means might be appropriate. Both types of monitoring are regulatory, and typically result in decisions regarding the solution process.

Protocol Scoring.

Each protocol was analyzed in terms of the processing events that have been outlined in the discussion of the question answering model. Specifically, individual actions were classified according to cognitive actions (recall, read, compare, monitor, evaluate) and information on which the event acted (text material, question, own knowledge). A full set of the cognitive actions used in coding is provided in Appendix B. Table 5, DW's protocol for question 12, 6, shows an example of the coded protocols that resulted from this procedure.

The next step in the data reduction process was to assign each coded question answering protocol to a solution strategy type by indicating the search type and the presence or absence of each of the "additional" processes. We adopted the convention of a 5-place code for solution strategy types, where the first place indicated the type of search(A - D) and the remaining four indicated the presence (1) or absence (0) of each of the processing events named in the columns in Table 7. Thus, the code B.1010 indicates a strategy involving text search, question analysis and process monitoring. Furthermore, a superscript gives the evaluation of the final answer produced by the learner, with 1 indicating correct, 2 indicating qualitatively correct (but not quantitatively) for those questions where a specific numerical value was requested, 3 indicating a partially correct answer, 4 an incorrect answer and 5 no answer given.

Question types

The solution strategy employed by the learner is a function of the question, the text and the learner's knowledge base. Five question types were identified based on an analysis of (1) the relationship between the question and text and (2) on the demands made on the knowledge base. Table 8 summarizes the five types and indicates how the 18 separate questions employed in the study were distributed across types.[2] In the first type of question there is a verbatim relationship between the question and the text. The text gives the answer explicitly and there is a direct match between the question wording and the text wording. Questions of this type may ask for quantitative answers, comparisons, explanations, conclusions, etc. In all cases, however, the learner merely has to locate the appropriate section in the text and find the matching language. In the particular sample of questions studied here, there were 5 instances of this type of question; for 3 of them, quantitative responses were appropriate, 1 required a comparison between quantitites and 1 asked for the properties of a concept.

The second type of question involves a paraphrase relationship between the question and the text. The text gives the answer explicitly if vocabulary equivalences and conversions are understood. Questions may vary with respect to the degree of conversion needed. Sometimes only one or two words might differ between the text and the question; other times the majority of the question wording might differ from that of the text. These conversions frequently depend on prior knowledge and assume that the learner already knows certain technical vocabulary (e.g. factor, ratio). Typically, however, once the appropriate vocabulary conversions are done and conceptual equivalences are established, the relevant text portion is relatively circumscribed and localized in one portion of the text. As with the first type of question, answers to these questions may involve quantitative responses, explanations, definitions, etc. There were four questions of this type, one of which required a quantitative response and three of which required explanations (Why?, How do we..., and How can...).

The third type of question, verbatim look-up plus comparison, involves reasoning with information found in the text. The text gives the necessary information explicitly and there is usually a direct match between the question wording and the text. Thus, locating the information proceeds much like in type 1 questions. However, once the information is "found", it must then be compared to other information. Sometimes concepts must be compared; other times quantities. In many questions of this type, a table or figure in the text will contain the information. There were three instances of this type of question in the oceanography sample, two of which involved locating and then comparing quantities; the third involved a comparison of two concepts.

The fourth type of question requires integration of information across several paragraphs of the text. There may be either a verbatim or paraphrase relationship between the question and the text but the text provides the relevant information in a number of paragraphs. The information must be coordinated and analyzed to construct the correct answer. These types of questions would lend themselves to partially correct answers if learners were to locate only one relevant section of text. In the oceanography sample there were 4 instances of this type of question. Three required explanations of concepts or processes and one requested the difference between two concepts. *In all four, there was a verbatim relationship between the text and the question, although the matching wording occurred in several paragraphs of the text.*

The last type of question requires reasoning, application and/or computation. Questions of this type involve using a text provided formula, rule or relationship to get the precisely correct answer. Locating the formula, rule or relationship involves a verbatim or paraphrase match or look up process. Answers to questions of this type cannot be found in the book directly. Rather, the learner must disembed the relevant information and apply it to a new situation described in the question. This type of question thus requires envisionment or comprehension levels that involve extending the text beyond its own confines whereas the other types of questions typically stay within localized portions of the text. In the oceanography sample, there were two examples of this question type. In the first, a quantitative response was to be determined using a formula provided in the text. However the symbols in the formula and their text-provided explanations did not directly match the terms given in the question. To make the correct equivalences, prior knowledge of the abbreviations used in the formula was necessary. This question thus also had elements of a type 2 question. The other question of type 5 also required a quantitative response. The learner had to determine the "next" value in a series that appeared in a table in the text. Thus, using the tabled values, one could determine the correct answer. Alternatively, the rule governing the entries in the table was given in the text and one could apply that rule directly to get the answer.

Predictions regarding the protocols

There is an expected ordering of difficulty for the five types of questions, with type 1 expected to be the easiest and type 5 the most difficult. Types 2, 3, and 4 were predicted to be roughly equivalent in difficulty. We also expected, based on the notion that the need for various processing events depends on the relation between the question and the text, solution strategies to reflect variations in task demands created by question factors (see also Reder, 1987, Experiment 6). Specifically, reasoning/inference and question analysis were predicted to occur less often for Type 1 questions as compared to the other types. We predicted that monitoring processess would occur more often for questions requiring multiple-source coordination, e.g., types 3, 4, and possibly 5.

Results and Discussion

Several important trends are reflected in the solution strategy data shown in Table 9. Consistent with an interactive comprehension model, task characteristics as reflected in the type of question, and learner characteristics, as reflected in domain expertise and in language proficiency, affected the nature of the solution strategies. The various types of questions were differentially difficult and there was evidence of the use of different strategies depending on the type of question.[3] Furthermore, individuals tended to be relatively consistent in their strategic approach to the task but individual differences were observed and were related to both domain expertise and to language background. Each of these trends is discussed below.

Task difficulty and question type

Question type difficulty was measured by the percent correct (or qualitatively correct) answers and is shown in the first row of Table 10. As predicted, Type 1 questions were the easiest: 89% of the answers were correct. Type 4 questions were also relatively easy, 71% correct. The unexpected ease with which these were solved is probably due to the verbatim relation that held between this sample of type 4 questions and the text. However, another sample of type 4 questions might involve vocabulary conversion as well as cross-paragraph integration, in which case they would probably be harder to solve. In this particular task context the difference between types 1 and 4 was the amount of text that matched the question, with type 4 questions matching over longer segments. Those question types requiring reasoning were successfully solved 62% (type 3) and 57% (type 5) of the time, whereas type 2 questions were the most difficult, 39% successful solutions. If one considers only successful quantitative solutions for type 5, 36% of the solutions were correct. Thus, the most difficult question type, type 2, was the type requiring knowledge of vocabulary and conceptual equivalence, primarily for technical, natural science and oceanography terms. Note that correct quantitative solutions for Type 5 questions also depended having on this type of knowledge (especially Chapter 2, 2) and the success rate was similarly low.

Solution strategies and question type

Learners engaged in different strategies depending on the type of question they were attempting to answer. For the type 1 questions, verbatim relation to text, 90% of the correct solutions involved a simple "search plus retrieve answer" strategy. Of these , 58% were text searches and 32% were memory searches. Furthermore, half of these single source searches involved no other processing events. Correct solutions to type 4 questions, which also featured verbatim relations to the text, were simple "search plus retrieve answer" strategies 85% of the time, but about half of these were text and half memory searches. The remaining 15% used both text and memory searches. Solution to the two types of verbatim questions differed principally in terms of the more frequent use of monitoring in the type 4 questions. In particular, for type 4 questions, 65% of the correct solutions (79% of all solutions) included process and/or product monitoring compared to 42% for Type 1 questions. Not surprisingly reasoning and inference processes rarely occurred for either type 1 or 4 questions. These data are summarized in Table 10.

Type 3 questions, verbatim "look up" plus comparison, were similar to type 1 and 4 questions in terms of the search strategies (85% search single source, 15% search both text and memory) used in correct solutions. Type 3 differed from types 1 and 4 in that 54% of the correct solutions employed reasoning and inference processes, a difference consistent with the nature of these questions. Type 3 differed from type 4 but was similar to type 1 in that 46% of the correct solutions featured monitoring, principally checking product or answer before stopping. Only 23% of the correct solutions (24% of all solutions) failed to include any of the four processing events beyond search and retrieval. Thus, for these three types of questions that all in some measure involve verbatim relations between text and question, there is a comparable degree of reliance on text and memory search leading to correct answer retrieval. Types 1 and 4 are similar to one another but different from type 3 on the use of reasoning; type 1 and 3 include less monitoring than type 4.

Correct solutions to type 5 questions, requiring use of a formula or rule given in the text, are distinguished from types 1, 4 and 3 in terms of the appearance of the disconfirming search strategy, i.e., the search leads to the realization that the answer is not "given" explicitly in the text but must be computed (search type D). In conjunction with this search type, process and product monitoring are very frequent in the correct solutions and are more frequent than in the three preceding types of questions. Similar to type 3, reasoning and inference occurred in 63% of the correct solutions. Solutions to type 5 questions rarely (13%) featured no additional processes, a marked difference from types 1 and 4.

Correct solutions to type 2 questions were a cross between type 1 and 4 solution strategies. Like type 1, 83% of the correct solutions involved searching one source and answering; like type 4, there was a high degree of monitoring (75% of the solutions). Note however, that these data represent only 39% of the attempted solutions. When correct, the successful vocabulary conversion allowed learners to treat these questions like verbatim questions. Given the high failure rate on Type 2 questions (61%), consideration of the solution strategies for both correct and incorrect final answers is informative. Over all solutions, the most frequent search strategy was a text search (17 of 28 solutions); however, 59% (10) of these failed to lead to correct solution. Another five memory search solutions (63% of 8 memory searches attempted) failed to lead to a correct solution. Two of three solutions using both sources failed. Despite the fact that the final answers were incorrect, learners did engage in question analysis (71% of the "incorrect" solutions) and monitoring (76% of the "incorrect" solutions). The inability to map the language of the question onto the language of the text appears to have been the critical obstacle to successful solution. We note that nonnative English and native English speakers' solutions resulted in correct answers equally often on this question type (42% and 38%, respectively). However, the solution attempts of the former group were more likely to be incorrect than those of the latter (50% versus 25%). The native English speakers' solutions resulted in partially correct answers 31% of the time but there were no partially correct answers for the nonnative English speakers. Thus, difficulties on this type of question may be related to English language proficiency. In addition, they are also substantially related to subject matter expertise differences and the impact of this factor on the solution strategies of individual ıearners.

Learner characteristics and solution strategy patterns

The learners examined in this study differed along several dimensions other than native language. In particular, and as noted in discussing Table 1, the hard science backgrounds of two of the native English speakers (MR and HS) qualified them as experts, or near experts, when dealing with the material in Chapters 2 and 12 of the Oceanography text. Their strategies for answering the questions differed from the other "novice" native English speakers and from the nonnative English speakers. However, one nonnative English speaker (GL) who had taken a science course in college (astronomy) also differed in approach from the two other nonnative English speakers (EH and II) and from the novice native English speakers (DW and LH). Table 11 presents the quantifiable characteristics of the solution strategies for each learner.

Considering first the two domain experts, MR and HS, we note a relatively strong reliance on memory searches, relatively little question analysis, and reasoning/inference in about one-third of the solutions. Both also engaged in monitoring on about half the solutions. The primary difference between MR and HS was in the rate of correct solutions: MR was correct 89% of the solutions compared to 67% for HS. This difference may be related to a difference in the type of monitoring done by MR -- largley checking to be sure the answer was complete -- compared to that used by HS -- largely keeping track of the progress of her efforts to solve a particular problem. Thus, MR's solution strategies included a preponderance of successful memory searches, answer confirmation processes and reasoning where appropriate, e.g., for question types 3 and 5. HS employed similar strategies, however she failed to monitor her answers very well and the outcomes of her efforts were less often accurate. Examining her protocols revealed a tendency to quit once she had produced an answer that met her acceptability criterion. As the TA for the course, HS may have been assuming, perhaps incorrectly, that she already knew many of the answers and thus, consulted the question and the text far less often than many of the other learners.

In contrast to HS, but like MR, GL had a high rate of successful solution. However, compared to both MR and HS, GL relied almost exclusively on text searches in his solutions. Furthermore, he engaged in frequent question analysis and monitoring (about 50% of the solutions). GL monitored both process and product. Two of the three questions that GL got wrong involved vocabulary conversion or paraphrase to successfully map the question to the text. On the whole, however, GL was generally highly successful in his use of the text.

The remaining four learners tended to be correct less often than MR, GL, or HS. LH was correct least often (44% of her solutions). Her solution strategies were characterized by *memory search or text search but little monitoring of either the process or products of search.* She engaged in a relatively high degree of question analysis and an average amount of reasoning and inference. LH appeared to engage in no cognitive activities that would have permitted her to reject or repair inadequate candidate answers and had the highest number of partially correct answers. The other "novices" each engaged in monitoring activities more frequently than did LH and were correct on 55% to 65% of their solutions. Of the three, II was the only one who had taken any physics courses. II's solution strategies reflected a cross between MR and GL with respect to search types. He tended to engage in more question analysis than MR and about the same degree of monitoring as GL and MR. II's lower accuracy rate was due largely to misreading and misinterpretations of the text and/or the questions. EH, the third nonnative English speaker, relied heavily on the text, as did GL; however her lack of science background prevented her from successfully solving type 5 questions and she had difficulty with type 3 questions. Similar to GL, type 2 questions that required paraphrase and vocabularly conversion presented particular difficulties for her.

Finally, DW, also a "low knowledge" learner, showed the most extensive use of monitoring of all seven learners. She employed both memory and text searches and frequently employed question analysis. DW tended to engage in lengthy text searches that were punctuated by overt consideration of the question and the relevance of specific text sections . Of DW's incorrect answers, 50% were partially correct and reflected inadequate background knowledge with which to evaluate her candidate answers.

The observed differences among the protocols can be summarized in the following way: The "expert" native English learners tended to rely on memory searches; the more successful learner engaged in optional answer confirmation. Of the lower knowledge native English speakers, one tended to rely on memory (LH) and had a high rate of incorrect answers. When she did search the text she found the correct answers only for Type 1 (verbatim) questions. Finally, DW relied on the text to a greater degree than the other native English speakers. Her solution strategies were extensive and quite often involved question analysis, monitoring and reasoning. In general, the nonnative English speakers relied on the text to a greater degree than the native English speakers. The highest knowledge and most successful nonnative English speaker, GL, relied almost exclusively on the text and engaged in frequent question analysis and monitoring activities. EH was less successful in her efforts to use the text and was hampered frequently by vocabulary/conceptual gaps. Finally, II used memory and text searches but was frequently hampered by faulty or inadequate question encoding or text interpretation.

The foregoing characterizations were based on the simple presence or absence of the various processing events. A complimentary analysis considered the frequency of various processing events. The frequency data index the length of solution. Two measures were computed from the coded protocols: number of processing events (read, reread, skim, etc.) and number of metacognitive processing events (monitor, evaluate, etc.). These data were used in conjunction with the data in Table 11 to develop summary profiles of the seven learners. These summaries are presented in Table 12.

The profiles help to illustrate the complex interactions of text, task and learner that were observed. The two most successful learners (MR and GL) differed in the length of solution, with GL engaging in twice as many metacognitive and cognitive processing events as MR. Whereas GL was high knowledge, he did not have MR's level of expertise and may therefore have relied more on the presented information than did MR. The two moderately successful learners, HS, the content expert, and DW, a novice geology student, replicated the differences between GL and MR. Thus, lacking expertise in the domain, learners who did well tended to extensively process the written material in the context of the question and to keep careful track of their performance.

In contrast, the three less-successful learners had in common a tendency to answer quickly, i.e. to engage in relatively short (few step) solutions. Comparison of EH and II revealed identical solution success rates but that metacognitve processing was twice as likely for the lower knowledge learner. Accuracy was lowest for the low knowledge, quick solver who engaged in virtually no metacognitive behavior.

The characterizations portrayed in these summary profiles suggest that successful learners may be sensitive to the need for strategies that compensate for low knowledge in a domain. Among these learners, the primary means of compensation was relatively lengthy text processing accompanied by monitoring and evaluation of the processes and products of solution. Nonnative English speakers who are sensitive to this compensatory mechanism, and attempt to use it, are heavily dependent on text negotiating strategies and on the necessary English language skills. In contrast, nonnative English speakers with high or expert levels of knowledge in an area would be less dependent on such English language skills.

Summary and Conclusions

The question-answering model plus the question taxonomy permit the analysis of learners solution strategies for dealing with academic text. The protocol analyses revealed a complex interaction of learner, text and task characteristics. Several important insights and tentative conclusions can be offerred. First, we found a great deal of similarity among the solution strategies of the native and nonnative English speakers, consistent with previous examinations of comprehension strategies of native and second language readers (Block, 1986a,b). However, one important difference that did emerge was a tendency for the nonnative English speakers to engage in more text searches and somewhat more question analysis than the native English speakers, as a group. Given the select and relatively high proficiency levels of the nonnative English speakers sampled in this study, were we to study a wider spectrum of nonnative English speakers, we would anticipate discovering solution strategy *differences* as well as replicating the difference we observed here. In this context, it is important to point out that despite extensive efforts to recruit volunteers from the oceanography course, a very small proportion of the enrollment was nonnative English speakers. Of these, there were only two other students who evidenced any desire to participate in the study but they were prevented from doing so by time constraints.

Solution strategy differences were related to expertise in oceanography and related science domains. Thus, this learner characteristic emerged as an important factor in question answering strategies. MR, our expert, was highly accurate and relied heavily on prior knowledge and memory search strategies. This type of solution strategy is consistent with previous accounts of the problem solving behavior of experts (e.g., Simon & Simon, 1976; Larkin,1980). Generally, the more successful learners, i.e., those who tended to get the correct answers, engaged in cognitive monitoring, especially of the products of their efforts, i.e., their answers or candidate answers. Unsuccessful solutions were associated with largely unmonitored memory searches and this was a particular obstacle for one of the "novice" native speakers. Finally, the task requirements, captured in the analysis of the types of questions occurring in the sample, determined solution strategy for all learners. The simplest strategies occurred for the verbatim questions, which had the highest rate of successful solution. There were few differences between language groups and/or expert-novice differences for these questions. The hardest question type was the one requiring vocabulary conversion and/or paraphrase matches between text and question. The expert was the only one maintaining highly accurate performance on these questions. The nonnative English speakers , especially the low knowledge one (EH), found these particularly difficult. The least successful, low knowledge native English speaker answered these questions incompletely or incorrectly as well.

Our speculation at this point regarding the relationship between knowledge, second language and answering questions from academic text is that difficulties encountered with specific text language may be overcome by a rich knowledge base. A hidden aspect of expertise in an area such as oceanography is the familiarity with general science terms and stylistic conventions employed by texts conveying scientific information. Certainly one area of particular interest is the role of different types of questions in facilitating academic learning. However, our work indicates that questions must be keyed to specific relations with the text if the appropriate envisionment level is to be attained. Questions that look like "think" questions can sometimes be answered correctly solely on the basis of the text. Other occasions arise where there is a hidden knowledge base requirement and one that is apparent only to a novice in the field. It is also clear from the way these learners used the text that the method of choice when the text is used is to read and reread sections that have a high number of words that match the wording of the question.

Further investigations of the role of text signals in facilitating comprehension and reasoning with academic material need to be pursued. Finally, the degree to which the strategies highlighted here generalize to academic learning and question answering with texts other than oceanography is an unknown at this time.

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Footnotes

1. We note that the subjects for this study volunteered to participate. The three nonnative English speakers were the only volunteers. Only two other students identified themselves to the research assistant as nonnative English speakers but they declined to participate due to the duration of the study. The native English speakers were the first three who volunteered and agreed to come to the laboratory in a timely fashion for all four experimental sessions.

2. From the original 6 questions per chapter, 18 separate questions were scored. One of the chapter 2 questions, #4, had to be dropped because the course instructor indicated that it was a poor question and not really answerable based on the information provided in the text.

3. The only difference between solutions for questions from chapter 2 (old) versus chapter 12 (new) was the somewhat higher incidence of memory and text searches ("C" strategies) for questions on "old" material. The old-new variable seemed to not otherwise affect solution strategies. This difference is consistent with the plausible prediction that questions on "old" material would seem more familiar and lead to a greater incidence of direct retrieval (cf. Reder, 1987). However, having retrieved an answer, there appeared to be sufficient uncertainty that subjects treated it as a candidate answer and searched the text prior to giving their final answer.

Table 1

Subject characteristics

Learner	Major	SAT (V/M)	Native Language	Self-rating: learning from English lecture	Self-rating: learning from English text	Self-rating: command of science vocab
HS[a]	Geology	NA	English	Extr. good	Extr. good	Extr. good
MR[b]	Physics	560/650	English	Good	Extr. good	Good
LH	Communications	990-both	English	Extr. good	Extr. good	Good
DW[c]	Sociology	550/590	English	Extr. good	Extr. good	Good
II	Bus./econ	380/540	Croatian	Good	Good	Moderate
EH	Bus./econ.	550/500	Dutch	Good	Extr. good	Moderate
GL	History	520/440	Spanish	Extr. good	Good	Moderate

[a]The teaching assistant for the course and a graduate student studying Oceanography.

[b]MR's background is heavily oriented to the hard sciences. He has already taken two other College level geology courses. In combination with his physics major, this background qualifies MR as a subject matter expert or near expert in the introductory course in Oceanography because many of the concepts and relationships are familiar to him from his other science courses.

[c]DW had had one year of foreign study in Chile and lists Spanish, French and Russian as other languages that she has knowledge of .

Table 2

Question Answering Model for Learning from Academic Texts

Processing Events	Goals
Encode Question	**Goal:** Determine the type of question **Goal:** Determine starting point(s) for searching for an answer.
Search Memory for Answer	**Goal:** Find a candidate answer that exceeds criterion for response. (Evaluate likelihood of success with continued search. If high, continue memory search; If low, try another means.) **Goal:** Determine alternate sources for answer. (Memory search may provide information that facilitates external search.)
Search External Source for Answer, e.g. Textbook	**Goal:** Delimit search space. (Use question and results of any memory search.) **Goal:** Find relevant information. **Goal:** Process the text information in the context of the task defined by the question.
Construct and Output Answer	**Goal:** Answer question completely. **Goal:** Match type of answer to type of question.
Optional Monitoring, e.g.,	**Confirm Answer** **Monitor quality of answer** **Self-Monitor**

Table 3

Expansion of Goals of Question Encoding

Goal: Determine the type of question.

Does the question require explanation?
comparison?
definition?
quantitative values?

Does the question require application of material to a new situation or to everyday life, i.e., life outside the textbook?

Means: Use the language in the question
e.g., How many.....?
What does ______mean?
Why....?
Use the task context and constraints, e.g.
Type of Situation (homework, in-class exam)
Form (fill-in, multiple choice, short essay, open ended and long response space)

Goal: Determine starting point(s) for search space.

Use technical terms and keywords in the question as entry points.

Table 4

Interdependent Goals in Textbook Processing

Goal: Delimit the search space.

Means: Use the results of question encoding and/or memory search.

Goal: Find information relevant to the question.

Means: Global Search: Scan/skim text. This may be exhaustive or self-terminating.

Guided Search: Use question keywords, topic, headings, subheadings to localize search.
Use "remembered" locations to localize search.

Goal: Process the text information in the context of the task defined by the question.

Means: Read, Reread
Rephrase, Paraphrase — the text and the question.
Summarize
Reason/Apply/Integrate

Table 5

DW's protocol for 12,6 Explanation question

Processing Event	Information	Comment/Interpretation
Reads	question	
Identifies	topic and text section	"Latent heat"
Rereads	question	
Recalls	answer from memory	Global answer. "Because of the evaporation process"
Questions	self - Why does process work that way?	
Describes	strategy = go to book	
Reads	text B.2 S29-S32	
Reads	text B.2S15	
States	answer	
Qualifies	answer (partially correct answer)	"I don't know- there's some thing in the book that I'm missing."
Skims	text from beginning of chapter through A.2 section	
Reads	text section B.1S1-S3	
Skims	text section B.1	
Reads	text section B.2S1-S6	
Recognizes	relevant information	on evaporation process
Rereads	text B.2S3-S6	
Reads	text B.2S7-S8	
States	answer that attempts to paraphrase what she's read	Not terribly different from initial guess.
Rereads	text B.2S7	
Decides/States	answer = original	Reverts to original answer

Table 6

Interrelated Goals of Answering

Goal: Answer the question completely.

Is there more information relevant to the question?
Has the extent of the search been sufficient?
Does the answer require further elaboration?

Goal: Match the type of answer to the type of question.

If the question asks for explanation
for comparison
for definition
for quantitative value(s)
has it been provided?

Goal: Demonstrate incorporation into the knowledge base.

Means: Construct an answer that does not match the textbook.

Use novel examples that demonstrate the questioned phenomena, concepts, or principles.

Table 7

Types of Solution Strategies

Encode question

Search types		Additional processing events			
		+question analysis	+reasoning, inference	+ process monitoring	+ product monitori
A.	memory search, answer retrieval A.000	A.1000	A.0100	A.0010	A.0001
B.	text search, answer retrieval B.000	B.1000	B.0100	B.0010	B.0001
C.	memory search, text search, answer retrieval C.0000	C.1000	C.0100	C.0010	C.0001
D.	text search (information is not "in" text), reason beyond text or compute answer D.0000	D.1000	D.0100	D.0010	D.0001

Output answer

Table 8

Question types and distribution of experimental questions across types

1. Verbatim relationship between the question and the text.

2, 3A: "What are..."	
12, 1A: "How many..."	quantitative response
12, 3A: "What fraction..."	quantitative response
12, 3C & D: "What (%)..."	quantitative response
12, 3E: "Does the difference (between quantities)..."	

2. Paraphrase relationship between the question and the text, including the necessity for vocabulary conversion and equivalence.

2, 1A: "How do we..."	
2, 1B: "Why ..."	
2,5: "How can..."	
12, 2A: "What is..."	quantitative response

3. Verbatim "look up" plus comparison.

12, 1B: "How does this compare..."	quantitative comparison
12, 1C: "How does this compare..."	quantitative comparison
12, 2B: "How does this compare..."	quantitative comparison
12, 5: "How are...similar?"	concept comparison

4. Cross paragraph integration.

2, 3B: "Explain (properties)..."	concepts	
2, 6: "Explain how..."		process
12, 4: "What is the difference between..."		concept comparison
12,6: "Explain why..."		concept and process.

5. Reasoning, application, computation questions.

2, 2: "How much..."	quantitative response. Formula; not all the necessary information is explicitly in the text.
12, 3B: "What..."	quantitative response. The value in a series must be determined. Alternatively, a rule tha is given verbatim in the text (see 12,3E) may be applied.

Table 9

Strategic Solution Types[a]

Question Type	GL	II	Learners EH	MR	HS	LH	DW
TYPE 1: Verbatim relationship between the question and the text.							
2,3A	B.1110^{1}	B.1001^{1}	C.0010^{1}	C.0001^{1}	A.1010^{4}	A.0000^{4}	C.1011^{1}
12,1A	B.0001^{1}	A.0000^{1}	A.0011^{1}	A.0001^{1}(tc)	A.0000^{1}	A.0000^{1}	A.0001^{1}
12,3A	B.1000^{1}	B.1000^{1}	A.1000^{1}	A.0000^{1}	B.0000^{1}	B.1000^{1}	A.1001^{1}
12,3C&D	B.0000^{1}	B.0000^{1}	B.0000^{1}	B.0000^{1}	B.0000^{1}	B.0000^{1}	B.0000^{1}
12,3E	B.0100^{1}	B.0100^{4}	B.1010^{5}	B.0100^{1}	B.0100^{1}	B.0000^{1}	A.0001^{1}
TYPE 2: Paraphrase relationship between the question and the text.							
2,1A	A.0000^{4}	A.0001^{4}(tc)	C.0010^{4}	B.1010^{5}	B.1010^{4}	A.1001^{3}	B.0011^{1}
2,1B	A.0000^{1}	B.0010^{5}	C.0100^{4}	B.0011^{1}	B.1010^{4}	A.1001^{3}	C.0000^{1}
2,5	B.0011^{1}	B.0000^{1}	B.1010^{1}	B.0001^{1}	A.1110^{3}	B.1010^{3}	B.1110^{3}
12,2A	B.1010^{4}	B.0000^{1}	B.1100^{4}	A.0000^{1}	A.0001^{1}(tc)	B.1100^{4}	B.1110^{4}
TYPE 3: Verbatim "look-up" plus comparison.							
12,1B&C	B.1100^{2}	A.0101^{2}	B.0000^{3}	C.0100^{1}	A.0100^{1}	A.1100^{2}	B.0100^{2}
12,2B	B.1100^{4}	B.0110^{4}	B.0000^{4}	A.0101^{1}	B.0100^{2}	B.1100^{4}	B.1110^{5}
12,5	B.0001^{1}	C.1011^{1}	A.0001^{1}	A.0000^{3}	A.0000^{1}	A.0000^{4}	A.0001^{1}(tc)

TYPE 4: Cross paragraph integration (verbatim and paraphrase relationships).							
2,3B	B.1110^{1}	B.0001^{3}	C.0011^{1}	C.0001^{1}	A.1010^{4}	A.0000^{4}	---
2,6	B.1011^{1}	A.1110^{4}	B.1000^{1}	A.0000^{1}	A.0000^{1}	B.1110^{3}	A.1001^{3}(tc)
12,4	B.0001^{1}	A.0000^{1}	B.0000^{1}	A.0000^{1}	A.0001^{1}	A.0001^{1}(tc)	C.1010^{1}
12,6	B.1001^{1}	A.0000^{1}	B.0000^{1}	A.0000^{1}	B.1010^{1}	A.0001^{1}(tc)	C.1011^{3}
TYPE 5: Reasoning, application, computation.							
2,2	A.0001^{2}(tc)	A.1101^{4}	B.0110^{5}	A.1101^{1}	A.0111^{1}	A.0000^{1}	B.1111^{2}
12,3B	B.1110^{1}	D.0010^{5}	D.1110^{4}	D.0111^{1}	D.0110^{4}	C.0110^{4}	D.0110^{2}

[a]Superscript indicates the outcome of the question answering process: 1 = correct answer; 2 = qualitatively correct for those questions actually requiring a quantitative answer; 3 = partially correct answer; 4 = incorrect answer; and 5 = no answer given. (tc) indicates that product monitoring involved using the text to confirm the final answer. Note that DW failed to attempt to answer one of the questions, an omission not caught or corrected by the experimenter.

Table 10

Strategies for correct solutions to the five types of questions[a]

	Question type				
	Type 1	Type 4	Type 3	Type 5	Type 2
Processing	(n=35)	(n=28)	(n=21)	(n=14)	(n=28)
Event					
Percent correct	(89%)	(71%)	(62%)	(57%)	(39%)
Search memory (Type A)	.32	.45	.54	.50	.25
Search text (Type B)	.58	.40	.31	.25	.58
Search memory and text (Type C)	.10	.15	.15	0	.08
Text search, reason beyond (Type D)	0	0	0	.25	0
No added processes	.45	.40	.23	.13	.42
Question analysis	.26	.30	.23	.25	.08
Reasoning/Inference	.13	.05	.54	.63	0
Monitoring[b]	.42	.65	.46	1.13	.75
Process	.13	.25	.08	.50	.33
Product	.29	.40	.38	.63	.42

[a]Percent correct solutions is given in parentheses for each type of question. Probabilities in the body of the table are based on the frequency of occurrence of each event in correct solutions.

[b]Underlined data in this row are the sums of the probability of process and product monitoring. Because both could occur in a protocol, the sums can exceed 1.00.

Table 11

Solution strategies for the seven learners[a]

	Learners						
	Native English			Nonnative English			
	MR	HS	DW	LH	GL	EH	II
Correct	16 (89%)	12 (67%)	12 (67%)	8 (44%)	15 (83%)	10 (55%)	10 (55%)
Search Type							
Memory	9 (8)	10 (7)	5 (4)	10 (5)	3 (2)	3 (3)	7 (4)
Text	5 (4)	7 (5)	7 (4)	7 (3)	15 (13)	10 (5)	9 (5)
Both	3 (3)	---	4 (2)	1 (0)	---	4 (2)	1 (1)
Compute	1 (1)	1 (0)	1 (1)	---	---	1 (0)	1 (0)
Added Processing Events							
None	7	5	2	7	1	5	6
Question analysis	2	2	9	8	9	6	5
Reasoning/inference	5	6	6	5	6	4	5
Monitoring[b]	_9_	_10_	_14_	_7_	_11_	_9_	_10_
Process	3	8	9	3	6	8	5
Product	8	3	9	4	6	3	6

[a]Maximum = 18. Frequencies in parentheses are the frequencies of correct solutions.

[b]These data are the number of solutions containing either process or product monitoring.

Table 12

Summary profiles of the seven oceanography learners

	Accuracy	Knowledge	Speed of solution	Monitoring
Successful learners				
MR	High	Expert	Quick	Moderate
	(89%)		(67 events)	(27 events)
GL[a]	High	High	Slow	High
	(83%)		(148 events)	(46 events)
Moderately successful learners				
HS	Moderate	Expert	Medium	Medium
	(67%)		(92 events)	(31 events)
DW	Moderate	Low	Slow	High
	(67%)		(172 events)	(76 events)
Less successful learners				
II[a]	Low	Medium	Quick	Low
	(55%)		(90 events)	(17 events)
EH[a]	Low	Low	Quick	Medium
	(55%)		(83 events)	(32 events)
LH	Low	Low	Quick	Low
	(44%)		(80 events)	(9 events)

[a]Nonnative English speakers

Appendix A: Texts, questions and answers used in the study.

B. PROBING THE EARTH'S INTERIOR

For a greater appreciation of the evolution of the earth and oceans as explained with plate tectonics, we must first understand the earth's structure. Studying the structure is fairly difficult because we must rely mainly on indirect techniques. Our mine shafts and boreholes only go down a few kilometers at most, so we only scratch the surface with our direct observations. Even if we could drill down to arbitrary depth, the material extracted would be in a completely different environment and, therefore, have very different properties than it had before we removed it. We sometimes try to study the properties of materials under high temperatures and pressures by putting a sample in a pressure vessel along with an explosive such as TNT. Even if we could sustain the high temperature and pressure for months, this time period would be "instantaneous" in comparison to the geological time scales of these environments within the earth. Slow transformations into more stable crystalline forms would not have sufficient time to take place, and so the materials would still have considerably different properties than their counterparts within the earth.

Most of our information concerning the earth's interior is gleaned indirectly, *using such things as the earth's gravitational field, or analyzing* the travels of seismic waves within the earth.

B.1 Gravity Studies

The force of gravity between two bodies depends on their masses, m_1 and m_2, and on the distance between them, r, according to

$$\text{Force} = G\frac{m_1 m_2}{r^2},$$

where "G" is just a constant of proportionality, called the "gravitational constant." This relationship says that the attractive gravitational force between two masses increases if either mass (m_1 or m_2) increases. For example, your weight would increase if, either: (1) you increased your mass, or (2) you went to a more massive planet. The relationship also indicates that the strength of the gravitational force between two objects *decreases* if their separation (r) is increased (Table 2.1).

"Gravitometers" are instruments made to measure small changes in *the earth's gravity from its average value. Since the force of gravity is* dependent on both masses and distances, an array of gravitometers can detect differences both in subsurface masses and in their distributions (Figure 2.8). These instruments are remarkably sensitive. For example, a change in elevation of just a few centimeters from the earth's center can easily be detected. If you've ever wondered how the elevation of a mountain above sea level could be so accurately measured, even if the mountain is a thousand kilometers inland, this is one way it is done.

Earth-orbiting satellites are also used to study the earth's internal structure. The orbits of the satellites are carefully observed. Any distribution of mass within the earth that differs from a purely concentric, spherically symmetric arrangement, will cause detectable changes in the satellite's orbit and speed. Satellites may also carry very sensitive altimeters that give us extremely accurate mappings of the topography of the earth's surface.

TABLE 2.1 Variation of Gravitational Acceleration with Altitude above Sea Level

Altitude (km)	*g m/s²*
0	9.806
1	9.803
10	9.776
100	9.60
1000	7.41
10,000	1.48
100,000	0.036

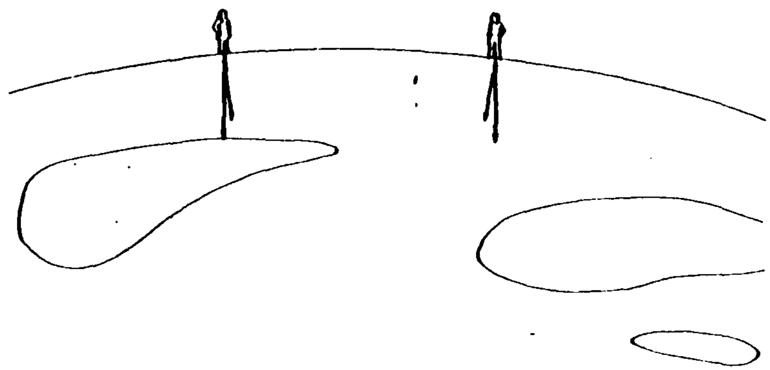

FIGURE 2.8 *Subsurface mass distribution can be studied by its influence on the gravitational field at the surface. In the above sketch, the actual gravitational force (black arrow) differs from the expected gravitational force (colored arrow) by a small amount due to the extra massive subsurface areas.*

Of course, just one measurement with one gravitometer or with the overhead passage of one satellite will not uniquely determine subsurface mass distributions. But people trained in appropriate mathematical techniques can use a large number of measurements to give us a fairly accurate picture of mass distributions within the earth.

B.2 Seismic Studies

Seismic waves are also an important tool used to probe the internal structure of the earth. Seismic waves originate in localized disturbances, usu-

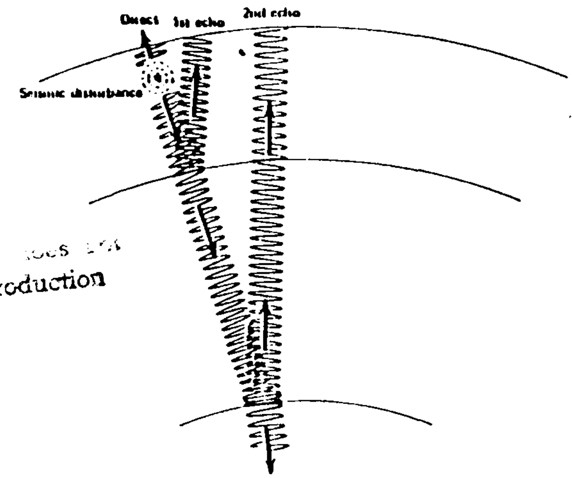

FIGURE 2.9 Seismometers record echos of the original seismic disturbance *because seismic waves reflect from subsurface interfaces. Later echos come from greater depths.*

ally within the earth's outer crust, such as from slippage along an earthquake fault or from an underground nuclear explosion. These vibrations travel through the earth and are received at seismographic stations on the surface in various parts of the world.

Seismic waves have two properties that make them extremely fruitful in revealing internal earth structure. One is that some of them are reflected when crossing an interface between two different materials. Light waves do the same thing, and we can see reflections on glass because some light is reflected at the interface between air and glass. This means, for example, that if you were manning a seismographic station above a local seismic disturbance, you would record a series of echoes returning from various interfaces deep within the earth (Figure 2.9). Successive echoes would correspond to successively deeper interfaces between layers within the earth.

If you wished to determine the depth of any particular interface, you would need to know both how long you had to wait for that echo and the speed with which the seismic wave traveled. The first item could be read from your seismograph, but there is no direct way to know the speed of seismic waves deep within the earth. Fortunately, this information may be inferred from data, due to the other important property of waves.

This second property is that they tend to bend, or "refract," toward regions where they move more slowly.[4] In analogy, when the wheels on

[4] This is true of all waves. In the chapter on ocean waves, we'll see this again.

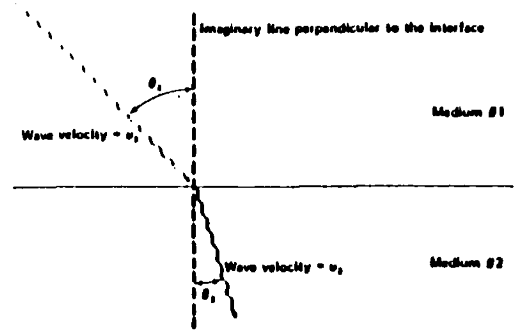

FIGURE 2.10 *According to Snell's Law, if a wave travels from one medium to another, and if its velocity in the first medium is v_1 and its velocity in the second medium is v_2, then the amount it is bent is determined by the following equation.*

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2}$$

one side of a car slip off the highway and onto the soft shoulder, the additional drag on these wheels makes them tend to slow down, and the car tends to steer toward this lower velocity region, unless the driver is alert and forces it back.

When a wave passes between two materials, there is an exact, known relationship between how much the wave gets bent and the speeds of the wave in the two materials. This is known as "Snell's law" (Figure 2.10). Through calculus, it can be generalized to find the wave trajectory through a material where the speed change is gradual and continuous. The result is that when a seismic wave travels through the earth, its trajectory is not a straight line, but rather is curved. The trajectory bends sharply at the interface between two materials, and slowly and continually within one material at various depths (Figure 2.11).

When a seismic wave arrives at a station a long way from the seismic disturbance, the time for arrival of that wave depends both on the trajectory of the wave through the earth and on the speed of the wave along that trajectory. But the two are not independent. The trajectory depends on the distribution of wave speeds within the earth. So the time for arrival of a seismic signal at a station gives a great deal of information on possible distributions of wave speed with depth in the earth. Knowing times of arrival at many different stations scattered throughout the world determines uniquely how the speed of seismic waves varies with the depth. From this information we learn something about the materials and environments at various depths. We can also use it to infer the depth of various interfaces from the delay times for echoes, as described previously.

Seismic waves traveling through the earth can be put into two categories (Figure 2.12). Those whose vibrations are parallel to the direction

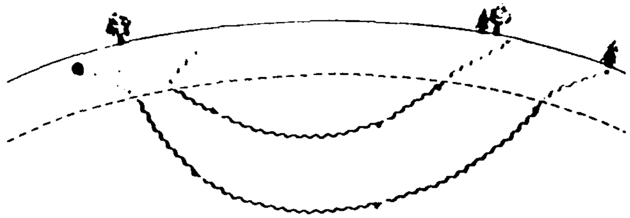

FIGURE 2.11 *Seismic waves travel curved trajectories through the earth because the wave speed changes with depth. Changes in wave speeds are caused by changes in materials, or by changes in temperature and pressure on the materials.*

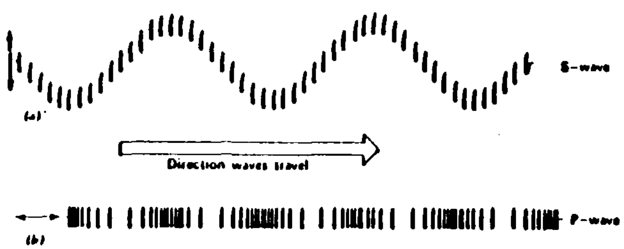

FIGURE 2.12 *Waves in a spring or "slinky." (a) When the motion of the individual links is perpendicular to the direction that the waves travel, they are S-waves (b) When the links move back and forth in the same dimension the waves travel, they are P-waves.*

of propagation are "P-waves." Those whose vibrations are perpendicular to the direction of propagation are called "S-waves." The "P" is for "primary," as the P-waves are fastest and reach the sensors before the slower, secondary "S"-waves. On a long spring or "slinky," a P-wave can be demonstrated by quickly moving one end in and out. An S-wave occurs when the end is wiggled sideways.

The P-waves can cross an interface between a solid and a liquid. For example, if you push the side of a container of water in and out, it will push the water in and out too. However, S-waves do not cross the interface. If you jiggle the side of a container of water back and forth, the water won't move, there's too little friction between the two. You can test this by spinning a glass of water back and forth and noting that although the solid container spins, the water doesn't. Liquids will not support shear stress.

It is found that stations on the opposite side of the earth from a disturbance receive only P-waves. This indicates the earth has a liquid core

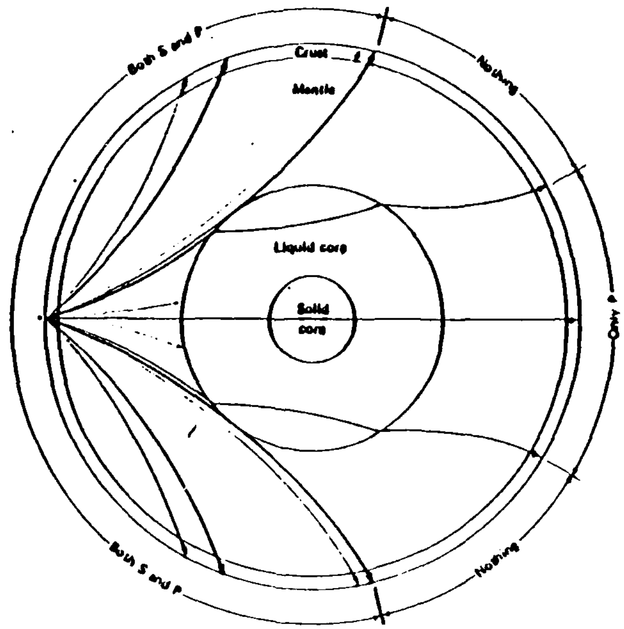

FIGURE 2.13 *Schematic diagram of the paths followed by P-waves (black lines) and S-waves (colored lines) through the earth's interior, after being generated at the left-hand side of the figure by some seismic disturbance. Notice that because the S-waves cannot cross the interface between the solid mantle and the liquid core, they will not be detected on the opposite side of the earth, arriving directly from the disturbance. In addition, due to refraction of the waves, there will be shadow zones where neither type of wave will be received directly.*

that prevents the direct arrival of S-waves through the earth's center. Of course, some will eventually arrive by traveling through the crust all the way around, or by some other circuitous route avoiding the core, but these will arrive much later, having traveled farther. By determining where S-waves are and are not received on the opposite side from a disturbance, we can map the outer border of the liquid core (Figure 2.13).

C. THE SHAPE OF THE EARTH

We know the shape of the earth from the use of conventional surveying techniques, and various types of altimeters. Recent advances in gravito-

12 THE OCEAN AND OUR CLIMATE

Compared to other terrestrial planets, the earth's climate is extremely mild. This is due to the abundance of surface water and its remarkable thermal properties.

Both ocean and atmosphere are only a few kilometers thick but extend completely around the earth. This makes their relative thickness in comparison to their breadth comparable to that of this sheet of paper. They are as intimately interconnected as are two successive pages in this book when the book is closed. Clearly their behaviors are closely related.

Although roughly equal in thickness, the oceans are 90 times more massive than the atmosphere, so it is really the oceans that control the atmosphere, and not vice versa. The oceans cover only 71% of the earth's surface. Over the 29% covered by continents, the atmosphere displays a little more caprice, being temporarily removed from the dominant moderating influence of the oceans.

In this chapter we study the earth's climate. Since it is controlled by the oceans, we must understand the oceans in order to understand our climate.

A. THE HYDROSPHERE

A.1 Water Reservoirs

The exterior of the earth is called the "hydrosphere." The hydrosphere has several types of water reservoirs, listed in Table 12.1. It may be somewhat surprising to us terrestrial beings, who rely so heavily on our water for our livelihood, that less than 8% of the water is stored in ground water and only a trace (.04%) in our beloved lakes and rivers. Furthermore, in spite of our sentiments during the rainy season, the atmosphere holds only a thousandth of a percent of the hydrosphere's water. If in one gigantic worldwide rainstorm all the atmosphere's water were to fall to the earth's surface, it would only amount to about 3 cm of rainfall. Practically all of the water (98%) is contained in the oceans, and most of the remainder is stored in the polar caps and other ice. Another way to visualize the relative amounts of water in the various reservoirs is to imagine that we could make the earth's surface perfectly smooth and spread out the water from each of these reservoirs evenly. Then the respective depths of the waters, called "sphere depths," would be those given in Table 12.1.

A.2 The Hydrologic Cycle

In spite of its low water content, the atmosphere serves as an important agent in the transfer of water from one reservoir to another. The cycling of water among the reservoirs is called the "hydrologic cycle," and is depicted schematically in Figure 12.1. The ocean loses water to the atmosphere via evaporation, but gains it back through precipitation,

TABLE 12.1 The Amount of Water in the Various Reservoirs, in Terms of Percent of Total (1.4 Billion km³), and in Terms of Sphere Depths

Reservoir	Percent of Total	Sphere Depth (m)
Oceans	97.00	2685
Polar caps and ice	1.64	45
Ground water	0.36	10
Rivers and lakes	0.04	1
Atmosphere	0.001	0.03

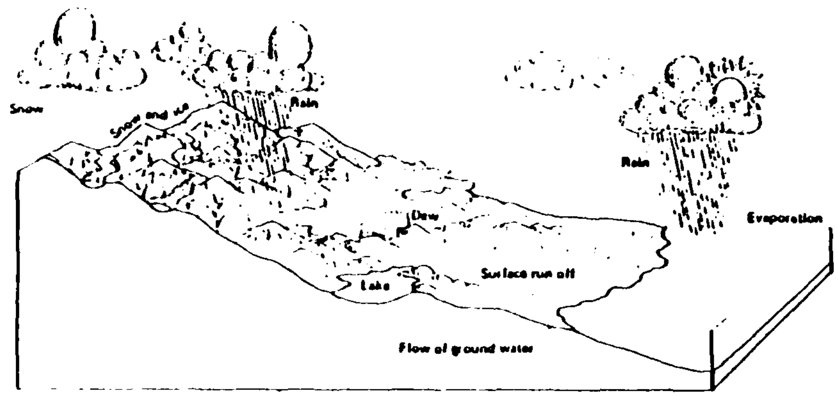

FIGURE 12.1 Hydrologic cycle, depicting some of the major mechanisms for the *transfer of water between reservoirs.*

run-off from the land, and melting of ice. The atmosphere carries some of the water from the oceans to the polar caps, where it is deposited as snow, and it deposits water on the continents via rainfall, snow, dew, and so on. Over the continents, the precipitation exceeds the evaporation, and so some of the water must be returned to the oceans via the rivers and underground flow.

II THE ATMOSPHERIC RESERVOIR

II.1 The Atmospheric Water Content

Everyone is aware that the water in an open pan will slowly evaporate. The warmer and drier the air, the faster the water will disappear. The amount of water vapor that air can hold depends on the temperature of the air, which increases roughly by a factor of two for every 10°C increase in the temperature. (See Table 12.2.) At room temperature (about 20°C) *the atmosphere can be up to 2.31% water vapor. There are several terms* dealing with the water content of air. We call air "saturated" if it is hold-

TABLE 12.2 Water Vapor Content of Saturated Air as a Function of the Temperature

Temperature (°C)	0°	5°	10°	15°	20°	25°	30°
Water vapor content when saturated	.60%	.86%	1.21%	1.68%	2.31%	3.10%	4.17%

ing as much water as it can (i.e., under normal conditions, or in equilibrium with liquid water). For example, if air at 25°C is 3.1% water vapor, then it is saturated. If you were to cool this air down to 15°C, then it would be "supersaturated)" and about half of the water would condense and precipitate out.[1] There are several terms for describing how much water there is in the air. "Absolute humidity" is simply the percentage of air that is water vapor. The "relative humidity" relates the actual water content to the maximum possible content. For instance, if air at 25°C were 3.1% water vapor, then the absolute humidity would be 3.1%, whereas the relative humidity would be 100%, as according to Table 12.2, that air would be saturated. If this same air held only half as much water as it could (e.g., 1.55% at 25°C), then the absolute humidity would be only 1.55%, and the relative humidity 50%. If air at 100% relative humidity is cooled, then it becomes supersaturated and the excess moisture precipitates. The "dew point" is that temperature at which the air will become saturated. For instance, if the water vapor content of a certain air mass is 1.68%, then the dew point is 15°C, as is seen from Table 12.2 that this is the temperature at which the air will be saturated. Notice that the dew point does not depend on the actual temperature of the air, only on its water content.

II.2 Latent Heat of Vaporization

It takes a lot of heat to evaporate water. We have seen that 1 calorie will raise the temperature of 1 g of water by 1°C. Therefore, it takes 100 calories to bring 1 g of water from its freezing point to boiling. But an additional 540 calories are required to actually evaporate the water. Thus, a pan of water on the stove readily comes to boiling, but takes a long time to boil dry. If it weren't for this we'd have difficulty boiling an egg or making soup. This is also why we perspire. The heat required to evaporate the water comes from our skins, cooling us off.

From a microscopic point of view, the following happens when water evaporates: Temperature is a measure of the average kinetic energy (energy of motion) of the molecules of a substance. At higher temperatures, the molecules are moving faster, on the average. Due to collisions between molecules, their motions are quite chaotic, and at any instant some will be moving faster than others. Some will be moving fast enough to burst free of the water surface and join the atmosphere as water vapor. These have "evaporated." At higher temperatures, more will be moving fast enough to evaporate, so the water evaporates faster at higher temperatures.

[1] *Actually, it could remain somewhat supersaturated if it did not come into contact with dust particles, ground, water droplets, or other condensation nuclei.*

Since the fastest moving molecules are the ones that evaporate, the ones left behind are slower moving, on the average, which means that the temperature of the remaining water is lower. This is why evaporation is a "cooling process," and why you feel cold when you step out of a shower. The fastest moving molecules join the atmosphere, taking their energy with them as "latent heat." They leave the slower moving ones behind so the remaining water is colder. If you wish to continue the evaporation, you must continually add heat to replace the energy removed by the evaporated molecules.

The heat given to water in evaporation is released again when it condenses. The condensing water vapor gives heat to our atmosphere during a rainstorm. So one way our atmosphere stores heat is in the latent heat of the evaporated water. At any one time relatively large quantities of heat are contained in the form of latent heat. As an example, a rainfall of 1 cm releases an amount of heat to the earth's surface and lower atmosphere that is equivalent to more than an entire day's sunshine. There is enough heat stored as latent heat in the earth's atmosphere right now to equal that received from the sun by the entire earth in four days.

It is sometimes convenient to divide the atmosphere's thermal energy into two components: "sensible heat" and "latent heat." Sensible heat is the thermal energy stored in the motion of the air molecules, and is reflected by the temperature. Latent heat is the energy stored in the evaporated water molecules, which is released when they condense into the liquid state.

Suppose we take a certain amount of water-saturated air and raise its temperature by 1°C. Some of the added heat would go into raising the temperature (sensible heat) and some into evaporating more water (latent heat). Although the required amount of sensible heat does not depend on the initial temperature of the air, the amount of latent heat does. For example, the same amount of sensible heat is required to raise the temperature from 10°C to 11°C as from 20°C to 21°C. But because the water content of saturated air increases exponentially with temperature, nearly doubling for every 10°C increase in temperature, we know that nearly twice as much water can evaporate when the temperature changes from 20° to 21°C as when the temperature changes from 10° to 11°C.

As the above example shows, at higher temperatures, relatively larger fractions of the added heat can go into evaporating water. (See Figure 12.2.) In fact, above 10°C, more added heat can be stored as latent heat than as sensible heat. This is quite remarkable, considering what a small fraction of the air is water vapor at these temperatures (Table 12.2)

11.3 Evaporation vs. Precipitation

Since the average water content of the atmosphere remains about the same from year to year, then the total precipitation in the world must equal the total evaporation. However, there are regional variations in this result. Over the oceans the evaporation exceeds precipitation, and over land the reverse is true. The excess of evaporation over precipitation

Chapter 2, 1:

How do we try to simulate conditions deep within the earth? b) Why is this not very satisfactory?

Answer according to instructor: a) Using a pressure vessel with an explosive. b) This is not very satisfactory because with the explosive, the high temperatures and pressures are created only for an instant. It is not a stable equilibrium situation as exists within the earth, and whatever measurements are to be made must be done instantaneously.

The answer is given in the very first paragraph of the section they were given to read: Part A is answered in BS5; part B in BS6, 7. However, the term simulate is not explicitly used. Thus, the student needs to understand the concept simulate and to recognize that a pressure vessel and an explosive, referred to in S5 would constitute such a simulation. *Simulation must be distinguished from the indirect and the direct methods* of study that are discussed in the same section of the text. The answer to part B is relatively easier to find because the text language conveys the dissatisfaction, e.g. Even if ...in comparison to ... within the earth; ...different propertion than ...within the earth.

A confusion on the part of a number of the students appeared when they tried to answer this question. A number of the answers indicated that indirect methods were inadequate for the reasons given for the simulation being inadequate. This interpretation actually contradicts the text. In fact, indirect methods are the main ways in which the interior of the earth is studied. The rest of the chapter goes on to discuss these indirect methods (Gravity studies, seismic waves, etc.).

Chapter 2, 2:

The moon has 1/80 as much mass as the earth and 1/4 the radius. How much would you weigh on the moon?

The text gives a formula that is needed to answer this question (Sect. B.1 S1-4). The definitions given for the terms in the equation do not match the question on the face of it so the substitutions that are needed are not transparent. For example, r is defined as the separation between two objects as well as the distance between to objects. How this relates to the question is not clear unless you know that r may be set equal to the earth's radius. Also, it is necessary to realize that the Gs can be ignored since they are constants.

Chapter 2,3:

What are two properties of seismic waves that tell us what the earth's interior is like? b) Explain them.

The two properties are reflection and refraction. They are explicitly marked as properties in the text: B.2S4, B.2S5 and B.2S12. They text provides explanations for each. For reflection, the text gives a comparison to light waves bending B.2S6; B.2S7, 8, 9 and 10 elaborate this example and discuss how the reflection property permits one to determine the internal structure of the earth. For refraction, the text gives an analogy to a car slipping off a highway (B.2S13); the next two paragraphs discuss the details of how refraction works to reveal structure (B.2S14 - S24). There are two figures illustrating reflection (Fig. 2.9) and refraction (Fig. 2.10 -- Snell's law.).

This section is followed by the introduction of two types of waves (S and P waves). The two types are differentially sensitive to materials in the earth's interior. Many students gave two types of waves instead of two properties. No students really got into the details of the refraction property.

Chapter 2,5:

How can satellites be used to get information regarding subsurface mass distributions?

Answer according to instructor: Any deviation from a spherically-symmetric distribution of masses within the earth will cause detectable changes in the satellite's orbit and speed.

This answer is virtually verbatim from the text: B.1S12. However, the meaning of this sentence is not transparent and the text does not use the term "subsurface mass distribution" in the body of the text. There is a Figure (2.8) right above this sentence that uses the term "subsurface mass distibution" and connects smd to gravitational fields at the surface. The *student must infer the relationship between orbiting satellites and* surface gravity and how variations in gravity affect the shape of the orbit and the speed of the satellite.

The text mentions one device, a gravitometer (B.1S5), that is used to measure changes in the earth's gravity from the average value. Also in B.1S13 the text refers to altimeters, which are instruments that map suface topography, not subsurface masses. "Using altimeters" or "with altimeters" is an incorrect answer by itself. In combination with a discussion of gravity and affects of subsurface mass on surface gravity, it was taken as correct.

Chapter 2, 6:

Briefly explain how "echoes" can be used to measure the depths of discontinuities in the earth's internal structure.

Answer according the the instructor: Seismic disturbances create waves, some of which reflect off of subsurface interfaces and come back toward the surface. As these "echoes" arrive at the surface, later arrival times mean they have traveled further, indicating deeper interfaces. Knowing time and speed, we can calculate distance.

-There is a simple and a complex answer to this question. The simple deals only with the time for the echo to come back. The complex answer deals with time and speed.

Relevant portions of the text: B.2 S4 - S10 plus Figure 2.9; B.2 S9 gives information for the simple answer. B.2 S19 - 25 deals with time and speed relationship.

Need to recognize that discontinuities is the same as interfaces between materials.

Chapter 12, Question #1:

If all the water in the atmosphere were to come out in one worldwide rainstorm, how many inches (or centimeters) of rainfall would it amount to? How does this compare to the water in the oceans? the ground water?

Answer supplied by instructor:

3cm. This is about 1/100,000 as much water as are in the oceans and about 1/360 as much water as is in ground water.

Sentence 5 in Section A.1 contains 3cm answer. Verbatim from text. Need to use Table 12.1 (pg. 324) to answer second part of the question.

Chapter 12, Question #2:

(a) What is the latent heat of vaporization of 1 g of water? (b) How does this compare to the heat required to bring it from freezing to boiling?

Answer given by instructor:

(a) 540 calories

(b) 5.4 times as great (100 calories are required to bring it from freezing to boiling and 540 calories are needed to vaporize it at 100°C).

Answer is given in S1- S4 under B.2 heading. *(page 325, first paragraph under heading.)*

Must understand

1) that evaporate = vaporization

2) that latent heat of vaporization = the amount of calories needed to evaporate water after it reaches boiling. This is not explicitly stated in the text. Either have to infer it or know it beforehand *(prior knowledge).*

Critical Text Language: additional 540 calories to evaporate.

Definition given in text *(S28 under B.2)*: Latent heat = energy in an evaporated water molecule, or energy available to be released when evaporated water molecule condenses.

To answer part b, must make a comparison between 540 and 100.

Chapter 12, #3 Question:

a) Suppose air at 25° C is saturated *(100% relative humidity)* what fraction of the air is water?

b) What would be the answer if the temperature were 35°?

c) 15°?

d) 5°?

e) Does the answer change by roughly a factor of 2 for every 10°?

Answers given by instructor:

a) 3.1%; b)About 6%; c)1.7% *(1.68%)*; d) .9% *(.86%)*

e) Yes *(actually just slightly less than a factor of 2).*

Answer to

a) is given in a text statement *(Under B.1, Sentence 7 p. 325)* and in Table 12.2, p. 325.

b) *must be computed either* by interpolation using Table 12.2 or by remembering the answer to e) and applying it to get the answer for 35° from 25°.

e) given verbatim in text -- Sentence 3 under the B.1 heading.

c) and d) are read directly from Table 12.2.

Answering this question also involves knowing what is not relevant. The text following Sentence 7 has many irrelevant numbers in it, as well as discussing at length issues associated with relative humidity. Also, understanding the vocabulary term factor is necessary.

Chapter 12, #4 Question:

What is the difference between "sensible heat" aand "latent heat" in the air?

Answer given by instructor:

Sensible heat is the heat that goes into raising the temperature of the air without increasing the water content, and latent heat is the heat that goes into evaporating more water into the air.

The answer is given directly in the text. One paragraph (Section B.2, paragraph 3) mentions the two concepts first and puts them in " "s. It defines them differently from the answer given by the instructor--or so it would seem. Then the next paragraph that starts with a "Suppose" and might suggest that a new topic is underway actually continues with an illustration and elaboration of the definitions and difference. The second sentence of that paragraph gives the answer that matches the instructor's (S30). Then in S31 an additional explicit difference is given ("Although the required amount of sensible heat does not depend on the initial temperature of the air, the amount of latent heat does.")

Chapter 12, Question #5 :

How are the oceans and the atmosphere similar to sheets of paper?

Answer: Ocean and atmosphere are only a few kilometers thick but go completely around the earth. Their relative thickness in comparison to their breadth is comparable to that of sheets of paper. They are also as interconnected as two successive pages in a closed book.

Answer comes from the second paragraph at the beginning of the chapter (page 323). This is a verbatim question.

Chapter 12, Question #6:

Explain why you feel cold when you get out of the shower.

Answer: Faster moving molecules leave skin and enter atmosphere, taking their energy and heat with them (they evaporate); slower moving are left behind. The slower moving have less energy and heat than the ones that leave.

Answer is given in Section B.2 Latent heat of vaporization but relevant information appears to be given in several different sections. At the end of the first paragraph (S7, 8); in the second paragraph and then again in the third. Each time, the language is a little different. Actually what the text does is to first state why we perspire (S7 & 8). Then in the next paragraph (S9 - 14), the scientific details of the process are given. Then in the third paragraph, the text makes the connection between the scientifically described process and the everyday experience (S15 - S18).
(S 9 - 14 explains process underlying molecule movement.)

Appendix B

Codes used in analyzing question answering protocols

The protocols were coded in terms of the cognitive (or metacognitive) action that was being carried out in reference to a type of information. Actions appearing on the same line (e.g., skim/scan) are functionally equivalent operations.

Action or Operation

Reads
Rereads
Paraphrases
Summarizes
Skims/scans
Searches
States
Re-states/repeats
Elaborates/Emphasizes
Qualifies
Describes (internal state)
Questions
Guesses
Recalls/Retrieves
Recognizes/Identifies
Locates/Finds
Compares/Detects
Infers/Reasons
Rejects
Concludes
Monitors
Evaluates
Confirms
Justifies

Information Type

Text material
Table, chart or figure
Question
Long term memory
Information from long term memory
Inferred information/conclusion
Own cognitive activity (including goals, obstacles, strategies)
Answer/candidate answer
Headings, Subheadings, boldface terms

Dr. Phillip L. Ackerman
University of Minnesota
Department of Psychology
Minneapolis, MN 55455

Dr. Beth Adelson
Department of Computer Science
Tufts University
Medford, MA 02155

AFOSR,
Life Sciences Directorate
Bolling Air Force Base
Washington, DC 20332

Dr. Robert Ahlers
Human Factors Lab., Code N711
Naval Training Systems Center
Orlando, FL 32813

Dr. Ed Aiken
Navy Personnel R&D Center
San Diego, CA 92152-6800

Dr. John R. Anderson
Department of Psychology
Carnegie-Mellon University
Pittsburgh, PA 15213

Dr. James Anderson
Brown University
Center for Neural Science
Providence, RI 02912

Dr. Steve Andriole
George Mason U/Info Tech & Eng
4400 University Dr.
Fairfax, VA 22030

Dr. Gary Aston-Jones
Dept. of Biology, N.Y.U.
1009 Main Bldg., Washington Sq.
New York, NY 10003

Dr. Patricia Baggett
Dept. of Psych., Box 345
University of Colorado
Boulder, CO 80309

Dr. Meryl S. Baker
Navy Personnel R & D Center
San Diego, CA 92152-6800

Dr. Eva L. Baker
Ctr. for the Study of Evaluation
145 Moore Hall, UCLA
Los Angeles, CA 90024

prof. dott. Bruno G. Bara
Unita di ricerca di intelligenza artificiale
Universita di Milano
20122 Milano - via F Sforza 23 ITALY

Dr. William M. Bart
Dept. of Ed. Psych., 330 Burton Hall
178 Pilsbury Dr., S.E.
Minneapolis, MN 55455

Leo Beltracchi
U. S. Nuclear Regulatory Comm.
Washington, DC 20555

Dr. Mark H. Bickhard
University of Texas
EDB 504 Ed. Psych
Austin, TX 78712

Dr. Gautam Biswas
Department of Computer Science
University of South Carolina
Columbia, SC 29208

Dr. John Black
Teachers College, Columbia Univ.
525 West 121st Street
New York, NY 10027

Dr. R. Darrell Bock
University of Chicago, NORC
6030 South Ellis
Chicago, IL 60637

Dr. Sue Bogner
Army Research Institute, (PERI-SF)
5001 Eisenhower Avenue
Alexandria, VA 22333-5600

Dr. Jeff Bonar
Learning R&D Center
University of Pittsburgh
Pittsburgh, PA 15260

Dr. Gordon H. Bower
Department of Psychology
Stanford University
Stanford, CA 94306

Dr. Robert Breaux
Code N-095R
Naval Training Systems Center
Orlando, FL 32813

Dr. Shirley Brice Heath
School of Education
Stanford University
Stanford, CA 94305

Dr. John S. Brown
XEROX Palo Alto Research Center
3333 Coyote Hill Road
Palo Alto, CA 94304

Dr. Ann Brown
Ctr for the Study of Reading
51 Gerty Drive, Univ of Illinois
Champaign, IL 61280

Dr. Bruce Buchanan
Computer Science Department
Stanford University
Stanford, CA 94305

Maj. Hugh Burns
AFHRL/IDE
Lowry AFB, CO 80230-5000

Dr. Patricia A. Butler
OERI
555 New Jersey Avenue, NW
Washington, DC 20208

Dr. Joseph C. Campione
Ctr. for the Study of Reading
51 Gerty Dr., Univ. of Illinois
Champaign, IL 61820

Joanne Capper
Center for Research into Practice
1718 Connecticut Ave., N.W.
Washington, DC 20009

Dr. Jaime Carbonell
Carnegie-Mellon University
Department of Psychology
Pittsburgh, PA 15213

Dr. Susan Carey
Harvard Grad. School of Ed.
337 Gutman Library, Appian Way
Cambridge, MA 02138

Dr. Pat Carpenter
Carnegie-Mellon University
Department of Psychology
Pittsburgh, PA 15213

LCDR Robert Carter
Office of the Chief of Naval
Operations, OP-01B, Pentagon
Washington, DC 20350-2000

Chair
Dept of Computer Sciences
U.S. Naval Academy
Annapolis, MD 21402

Chair
Department of Psychology
Towson State University
Towson, MD 21204

Chair, Department of
Computer Science
Towson State University
Towson, MD 21204

Chair, Dept of Psych
The Johns Hopkins University
Baltimore, MD 21218

Chair, Dept of Psych
College of Arts and Sciences
Catholic University of America
Washington, DC 20064

Chair, Dept of Psych
Georgetown University
Washington, DC 20057

Chair, Dept of Psych
George Mason University
Fairfax, VA 22030

Dr. Fred Chang
Navy Personnel R&D Center
Code 51
San Diego, CA 92152-6800

Dr. Davida Charney
English Department
Penn State University
University Park, PA 16802

Dr. Paul R. Chatelier
OUSDRE
Pentagon
Washington, DC 20350-2000

Dr. Michelene Chi
University of Pittsburgh, L.R.D.C.
3939 O'Hara Street
Pittsburgh, PA 15213

Dr. L. J. Chmura
Comp. Sci. and Syst. Branch
Naval Research Lab.
Washington, DC 20375-5000

Mr. Raymond E. Christal
AFHRL/MOE
Brooks AFB
San Antonio, TX 78235

Dr. Yee-Yeen Chu
Perceptronics, Inc.
21111 Erwin Street
Woodland Hills, CA 91367-3713

Dr. William Clancey
Knowledge Syst. Lab., Stanford U.
701 Welch Rd., Bldg. C
Palo Alto, CA 94304

Dr. Charles Clifton
Dept of Psych, Tobin Hall
University of Massachusetts
Amherst, MA 01003

Dr. Allan M. Collins
Bolt Beranek & Newman, Inc.
50 Moulton Street
Cambridge, MA 02138

Dr. Stanley Collyer
Office of Naval Tech., Code 222
800 North Quincy Street
Arlington, VA 22217-5000

Dr. William Crano
Department of Psychology
Texas A&M University
College Station, TX 77843

Bryan Dallman
3400 TTW/TTGXS
Lowry AFB, CO 80230-5000

Dr. Laura Davis
NRL/NCARAI Code 7510
4555 Overlook Ave., S.W.
Washington, DC 20375-5000

Defense Technical
Information Center (Attn. T. C.)
Cameron Station, Bldg. 5
Alexandria, VA 22314 (12 copies)

Dr. Natalie Dehn
Dept. of Comp. and Info. Science
University of Oregon
Eugene, OR 97403

Dr. Gerald F. DeJong
A.I. Grp., Coordinated Sci. Lab.
University of Illinois
Urbana, IL 61801

Geory Delacote
Dir. de L'info. Sci. et Tech., CNRS
15, Quai Anatole France
75700 Paris FRANCE

Department
of Computer Science
Naval Postgraduate School
Monterey, CA 93940

Dr. Sharon Derry
Department of Psychology
Florida State University
Tallahassee, FL 32303

Director
Manpower and Personnel Lab
NPRDC (Code 06)
San Diego, CA 92152-6800

Director
Training Laboratory
NPRDC (Code 05)
San Diego, CA 92152-6800

Director, Human Factors
& Organizational Systems Lab
NPRDC (Code 07)
San Diego, CA 92152-6800

Dr. Andrea A. diSessa
School of Education, EMST
University of California
Berkeley, CA 94720

Dr. R. K. Dismukes
Associate Director for Life Sciences
AFOSR, Bolling AFB
Washington, DC 20332

Dr. Stephanie Doan
Code 6021
Naval Air Development Center
Warminster, PA 18974-5000

Dr Emanuel Donchin
University of Illinois
Department of Psychology
Champaign, Il 61820

Dr. Thomas M. Duffy
Communications Design Center
CMU, Schenley Park
Pittsburgh, PA 15213

Dr. Richard Duran
School of Education
University of California
Santa Barbara, CA 93106

Dr. John Ellis
Navy Personnel R&D Center
San Diego, CA 92252

Dr. Susan Embretson
University of Kansas
Psych. Dept., 426 Fraser
Lawrence, KS 66045

Dr. Randy Engle
Department of Psychology
University of South Carolina
Columbia, SC 29208

Dr. Susan Epstein
Hunter College
144 S. Mountain Avenue
Montclair, NJ 07042

ERIC Facility
Acquisitions
4833 Rugby Avenue
Bethesda, MD 20014

Dr. K. Anders Ericsson
University of Colorado
Department of Psychology
Boulder, CO 80309

Dr. Jean Claude Falmagne
Department of Psychology
New York University
New York, NY 10003

Dr. Beatrice J. Farr
Army Research Institute
5001 Eisenhower Avenue
Alexandria, VA 22333

Dr. Pat Federico
Code 511
NPRDC
San Diego, CA 92152-6800

Dr. Paul Feltovich
So Illinois Univ, Sch of Med
Med Educ Dept, P.O. Box 3926
Springfield, IL 62708

Mr. Wallace Feurzeig
Ed Tech Ctr, Bolt Beranek & Newman
10 Moulton Street
Cambridge, MA 02238

Dr. Gerhard Fischer
Department of Psychology
University of Colorado
Boulder, CO 80309

Fleet Support Office,
NPRDC (Code 301)
San Diego, CA 92152-6800

J. D. Fletcher
9931 Corsica Street
Vienna, VA 22180

Dr. Linda Flower
Carnegie-Mellon University
Department of English
Pittsburgh, PA 15213

Dr. Kenneth D. Forbus
Dept of Comp Sci, U of Illinois
1304 West Springfield Avenue
Urbana, IL 61801

Dr. Barbara A. Fox
University of Colorado
Department of Linguistics
Boulder, CO 80309

Dr. John R. Frederiksen
Bolt Beranek & Newman
50 Moulton Street
Cambridge, MA 02138

Dr. Norman Frederiksen
Educational Testing Service
Princeton, NJ 08541

Dr. Michael Friendly
Psych Dept, York University
Toronto Ontario
CANADA M3J 1P3

Julie A. Gadsden
Info Tech and Applications Div
Admiralty Research Est
Portsdown, Portsmouth PO6 4AA U.K.

Dr. Michael Genesereth
Stanford University
Computer Science Department
Stanford, CA 94305

Dr. Dedre Gentner
Dept of Psych, U of Illinois
603 E Daniel Street
Champaign, IL 61820

Dr. Robert Glaser
University of Pittsburgh, LRDC
3939 O'Hara Street
Pittsburgh, PA 15260

Dr. Arthur M. Glenberg
WJ Brogden Psych Bldg
1202 W Johnson St, U of Wisconsin
Madison, WI 53706

Dr. Sam Glucksberg
Dept of Psych, Green Hall
Princeton University
Princeton, NJ 08540

Dr. Susan Goldman
University of California
Santa Barbara, CA 93106

Dr. Sherrie Gott
AFHRL MODJ
Brooks AFB, TX 78235

Dr. T. Govindaraj
Georgia Institute of Technology
Sch of Industrial & Syst Eng
Atlanta, GA 30332

Dr. Wayne Gray
Army Research Institute
5001 Eisenhower Avenue
Alexandria, VA 22333

Dr. James G. Greeno
School of Education
Stanford University
Stanford, CA 94305

Dr. Dik Gregory
Behavioral Sciences Division
Admiralty Research Est.
Teddington, Middlesex ENGLAND

Dr. Gehard Grossing
Atominstitut
Schuttelstrasse 115
Vienna, AUSTRIA a-1020

Prof. Edward Haertel
School of Education
Stanford University
Stanford, CA 94305

Dr. Henry M. Halff
Halff Resources, Inc.
4918 33rd Road, North
Arlington, VA 22207

Dr. Ronald K. Hambleton
Prof of Ed and Psych
U of Mass at Amherst, Hills House
Amherst, MA 01003

Steve Harnad, Editor
The Behavioral and Brain Sciences
20 Nassau Street, Suite 240
Princeton, NJ 08540

Dr. Wayne Harvey
SRI International
333 Ravenswood Ave, Rm B-S324
Menlo Park, CA 94025

Dr. Reid Hastie
Northwestern University
Department of Psychology
Evanston, IL 60201

Professor John R. Hayes
Carnegie-Mellon University
Dept of Psychology, Schenley Park
Pittsburgh, PA 15213

Dr. Barbara Hayes-Roth
Dept of Computer Science
Stanford University
Stanford, CA 94305

Dr. Frederick Hayes-Roth
Teknowledge
525 University Avenue
Palo Alto, CA 94301

Dr. Joan I. Heller
505 Haddon Road
Oakland, CA 94606

Dr. Jim Hollan
Intelligent Systems Group
Inst for Cog Sci (C-015), UCSD
La Jolla, CA 92093

Dr. Melissa Holland
ARI for the Behavioral and Soc Sc:
5001 Eisenhower Ave.
Alexandria, VA 22333

Dr. Keith Holyoak
Human Performance Center
U of Michigan, 330 Packard Rd.
Ann Arbor, MI 48109

Ms. Julia S. Hough
Lawrence Erlbaum Associates
6012 Greene Street
Philadelphia, PA 19144

Dr. James Howard, Dept of Psych
Human Performance Lab.
Catholic University of America
Washington, DC 20064

Dr. Earl Hunt
Department of Psychology
University of Washington
Seattle, WA 98105

Dr. Ed Hutchins
Intelligent Systems Group
Inst for Cog Sci (C-015), UCSD
La Jolla, CA 92093

Dr. Barbara Hutson
Virginia Tech Graduate Center
2990 Telestar Ct.
Falls Church, VA 22042

Dr. Barbel Inhelder
University of Geneva
Geneva SWITZERLAND 12U-4

Dr. Dillon Inouye
WICAT Education Institute
Provo, UT 84057

Dr. Alice Isen
Department of Psychology
University of Maryland
Catonsville, MD 21228

Dr. Robert Jannarone
Department of Psychology
University of South Carolina
Columbia, SC 29208

Dr. Claude Janvier, Directeur, CIRAI
Universite' du Quebec a Montreal
Montreal, Quebec H3C 3P8
CANADA

Dr. Robin Jeffries
Hewlett-Packard Laboratories
P.O. Box 10490
Palo Alto, CA 94303-0971

Dr. Robert Jernigan
Decision Resource Systems
5595 Vantage Point Road
Columbia, MD 21044

Margaret Jerome
c/o Dr. Peter Chandler
83, The Drive
Hove, Sussex UNITED KINGDOM

Dr. Douglas A. Jones
Thatcher Jones Assoc.
P.O. Box 6640, 10 Trafalgar Ct.
Lawrenceville, NJ 08648

Dr. Marcel Just
Carnegie-Mellon University
Dept of Psych, Schenley Park
Pittsburgh, PA 15213

Dr. Daniel Kahneman
The U of BC, Dept of Psych
#154-2053 Main Mall
Vancouver, BC CANADA V6T 1Y7

Dr. Ruth Kanfer
Dept of Psych, Elliot Hall
75 E River Rd, U of Minnesota
Minneapolis, MN 55455

Dr. Mary Grace Kantowski
University of Florida, Math Ed
359 Norman Hall
Gainesville, FL 32611

Dr. Milton S. Katz
Army Research Institute
5001 Eisenhower Avenue
Alexandria, VA 22333

Dr. Frank Keil
Department of Psychology
Cornell University
Ithaca, NY 14853

Dr. Wendy Kellogg
IBM T. J. Watson Research Center
P.O. Box 218
Yorktown Heights, NY 10598

Dr. Dennis Kibler
Dept of Info and Comp Sci
University of California
Irvine, CA 92717

Dr. David Kieras
Tech Comm, Coll of Engineering
1223 E. Engineering Bldg, U of MI
Ann Arbor, MI 48109

Dr. Peter Kincaid
Training Analysis & Eval Group
Department of the Navy
Orlando, FL 32813

Dr. Walter Kintsch
Dept of Psych, Campus Box 345
University of Colorado
Boulder, CO 80309

Dr. David Klahr
Carnegie-Mellon University
Dept of Psych, Schenley Park
Pittsburgh, PA 15213

Dr. Mazie Knerr
Training Research Div, HumRRO
1100 S. Washington
Alexandria, VA 22314

Dr. Janet L. Kolodner
Georgia Institute of Technology
School of Info & Comp Sci
Atlanta, GA 30332

Dr. Stephen Kosslyn
Harvard U, 1236 William James H...
33 Kirkland St.
Cambridge, MA 02138

Dr. Kenneth Kotovsky, Dept of Psych
Comm Coll of Allegheny Co
800 Allegheny Avenue
Pittsburgh, PA 15233

Dr. David H. Krantz
2 Washington Square Village
Apt. #15J
New York, NY 10012

Dr. Benjamin Kuipers
U of TX at Austin, Dept of Comp Sci
T.S. Painter Hall 3.28
Austin, TX 78712

Dr. David R. Lambert
Naval Ocean Syst Ctr, Code 41...
271 Catalina Boulevard
San Diego, CA 92152-6800

Dr. Pat Langley
Dept of Info & Comp Sci
University of California
Irvine, CA 92717

Dr. Marcy Lansman
U of NC, Davie Hall 013A
The L.L. Thurstone Lab.
Chapel Hill, NC 27514

Dr. Jill Larkin
Carnegie-Mellon University
Department of Psychology
Pittsburgh, PA 15213

Dr. Jean Lave
School of Social Sciences
University of California
Irvine, CA 92717

Dr. Robert Lawler
Information Sciences, FRL
GTE Labs, Inc., 40 Sylvan Road
Waltham, MA 02254

Dr. Alan M. Lesgold
University of Pittsburgh, LRDC
3939 O'Hara Street
Pittsburgh, PA 15260

Dr. Jim Levin
Dept of Ed Psych, 210 Ed Bldg
1310 So Sixth St
Champaign, IL 61810-6990

Dr. John Levine
University of Pittsburgh, LRDC
3939 O'Hara Street
Pittsburgh, PA 15260

Dr. Michael Levine
Ed Psych, 210 Education Bldg
University of Illinois
Champaign, IL 61820

Matt Lewis
Department of Psychology
Carnegie-Mellon University
Pittsburgh, PA 15213

Dr. Clayton Lewis
Dept of Comp Sci, Campus Box 430
University of Colorado
Boulder, CO 80309

Library
Naval Training Systems Center
Orlando, FL 32813

Library, NPRDC
Code P201L
San Diego, CA 92152-6800

Dr. Jane Malin
Mail Code SR 111
NASA Johnson Space Center
Houston, TX 77058

Dr. William L. Maloy
Chief of Naval Education
and Training, Naval Air Station
Pensacola, FL 32508

Dr. Sandra P. Marshall
Department of Psychology
San Diego State University
San Diego, CA 92182

Dr. Manton M. Matthews
Department of Computer Science
University of South Carolina
Columbia, SC 29208

Dr. Richard E. Mayer
Department of Psychology
University of California
Santa Barbara, CA 93106

Dr. Joe McLachlan
Navy Personnel R&D Center
San Diego, CA 92152-6800

Dr. James McMichael
Assistant for MPT Research,
Dev, and Studies, OP-01B7
Washington, DC 20370

Dr. Barbara Means
Human Resources Research Org
1100 South Washington
Alexandria, VA 22314

Dr. Douglas L. Medin
Dept of Psych, U of Illinois
603 E. Daniel Street
Champaign, IL 61820

Military Asst for Training
& Personnel Tech, OUSD (R & E)
Room 3D129, The Pentagon
Washington, DC 20301-3080

Dr. George A. Miller
Dept of Psych, Green Hall
Princeton University
Princeton, NJ 08540

Dr. William Montague
NPRDC Code 13
San Diego, CA 92152

Dr. Allen Munro
Behavioral Tech Labs - USC
1845 S. Elena Avenue, 4th Floor
Redondo Beach, CA 90277

Dr. AllenNewell
Carnegie-Mellon University
Dept of Psych, Schenley Park
Pittsburgh, PA 15213

Dr. Richard E. Nisbett
University of Michigan
Inst for Social Research, Rm. 5261
Ann Arbor, MI 48109

Dr. Mary Jo Nissen
University of Minnesota
N218 Elliott Hall
Minneapolis, MN 55455

Dr. Harold F. O'Neil, Jr.
School of Ed, WPH 801
Dept of Ed Psych & Tech - USC
Los Angeles, CA 90089-0031

Dr. Michael Oberlin
Naval Training Systems Center
Code 711
Orlando, FL 32813-7100

Office of Naval Research
Code 1142
800 North Quincy Street
Arlington, VA 22217-5000

Office of Naval Research
Code 1133
800 North Quincy Street
Arlington, VA 22217-5000

Dr. Stellan Ohlsson
University of Pittsburgh, LRDC
3939 O'Hara Street
Pittsburgh, PA 15213

Dr. Judith Orasanu
Army Research Institute
5001 Eisenhower Avenue
Alexandria, VA 22333

Professor Seymour Papert
20C-109
MIT
Cambridge, MA 02139

Dr. James Paulson
Dept of Psych, Portland State U
P. O. Box 751
Portland, OR 97207

Dr. Roy Pea
Bank Street College of Education
610 West 112th Street
New York, NY 10025

Dr. Douglas Pearse
DCIEM
Box 2000
Downsview, Ontario CANADA

Dr. James W. Pellegrino
Department of Psychology
University of California
Santa Barbara, CA 93106

Dr. Virginia E. Pendergrass
Code 711
Naval Training Systems Center
Orlando, FL 32813-7100

Dr. David N. Perkins
Educational Technology Center
337 Gutman Library, Appian Way
Cambridge, MA 02138

Dr. Nancy Perry, Chief
Naval Ed. and Training, Code 00A2A
Naval Station Pensacola
Pensacola, FL 32508

Dr. Steven Pinker
Deparment of Psychology
E10-018, MIT
Cambridge, MA 02139

Dr. Tjeerd Plomp
Twente U of Tech, Dept of Ed
P.O. Box 217, 7500 AE ENSCHEDE
THE NETHERLANDS

Dr. Martha Polson
Dept of Psych, Campus Box 346
University of Colorado
Boulder, CO 80309

Dr. Peter Polson
University of Colorado
Department of Psychology
Boulder, CO 80309

Dr. Steven E. Poltrock
MCC, Echelon Bldg #1
9430 Research Blvd
Austin, TX 78759-6509

Dr. Harry E. Pople
U of Pittsburgh, Decision Syst Lab
1360 Scaife Hall
Pittsburgh, PA 15261

Dr. Mary C. Potter
Department of Psychology
MIT (E-10-032)
Cambridge, MA 02139

Dr. Joseph Psotka
ATTN: PERI-1C
Army Research Institute
5001 Eisenhower Avenue

Psychologist
Office of Naval Research
Branch Office, London, Box 39
FPO New York, NY 09510

Psychologist
Office of Naval Research
Liaison Office, Far East
APO San Francisco, CA 96503

Dr. Lynne Reder
Department of Psychology
Carnegie-Mellon University
Schenley Park

Dr. James A. Reggia
Sch of Med, Dept of Neurology
22 So Greene St, U of Maryland
Baltimore, MD 21201

Dr. Frederick Reif
Physics Department
University of California
Berkeley, CA 94720

Dr. Lauren Resnick
University of Pittsburgh, LRDC
3939 O'Hara Street
Pittsburgh, PA 15213

Dr. Gil Ricard
Mail Stop C04-14
Grumman Aerospace Corp.
Bethpage, NY 11714

Mark Richer
1041 Lake Street
San Francisco, CA 94118

Dr. Mary S. Riley
Program in Cognitive Science
Ctr for Human Info Processing, UCSD
La Jolla, CA 92093

Dr. Linda G. Roberts, Sci, Ed, & Trans Prog, Tech Assessment
Congress of the United States
Washington, DC 20510

Dr. William B. Rouse
Search Technology, Inc.
25-b Technology Park/Atlanta
Norcross, GA 30032

Dr. David Rumelhart
Ctr. for Human Info. Processing
University of California
La Jolla, CA 92093

Dr. Roger Schank
Comp Sci Dept, Yale University
P.O. Box 2158
New Haven, CT 06520

Dr. Walter Schneider
University of Pittsburgh, LRDC
3939 O'Hara Street
Pittsburgh, PA 15260

Dr. Alan H. Schoenfeld
Department of Education, EMST
University of California
Berkeley, CA 94720

Dr. Janet Schofield
University of Pittsburgh, LRDC
3939 O'Hara Street
Pittsburgh, PA 15260

Karen A. Schriver
Department of English
Carnegie-Mellon University
Pittsburgh, PA 15213

Dr. Judah L. Schwartz
MIT
20C-120
Cambridge, MA 02139

Dr. Marc Sebrechts
Department of Psychology
Wesleyan University
Middletown, CT 06475

Dr. Judith Segal
OERI
555 New Jersey Avenue, NW
Washington, DC 20208

Dr. Sylvia A. S. Shafto
Department of Computer Science
Towson State University
Towson, MD 21204

Dr. Ben Shneiderman
Department of Computer Science
University of Maryland
College Park, MD 20742

Dr. Lee Shulman
Stanford University
1040 Cathcart Way
Stanford, CA 94305

Dr. Robert Siegler
Carnegie-Mellon University
Dept of Psych, Schenley Park
Pittsburgh, PA 15213

Dr. Derek Sleeman
Stanford University
School of Education
Stanford, CA 94305

Dr. Edward E. Smith
Bolt Beranek & Newman, Inc.
50 Moulton Street
Cambridge, MA 02138

Dr. Richard E. Snow
Department of Psychology
Stanford University
Stanford, CA 94306

Dr. Elliot Soloway
Comp Sci Dept, Yale University
P.O. Box 2158
New Haven, CT 06520

Dr. Richard Sorensen
Navy Personnel R & D Center
San Diego, CA 92152-6800

Special Asst for Marine Corps Matters, ONR Code 00MC
800 North Quincy Street
Arlington, VA 22217-5000

Dr. Kathryn T. Spoehr
Brown University
Department of Psychology
Providence, RI 02912

Dr. Robert Sternberg
Dept of Psych, Yale University
Box 11A, Yale Station
New Haven, CT 06520

Dr. Albert Stevens
Bolt Beranek & Newman, Inc.
10 Moulton Street
Cambridge, MA 02238

Dr. Thomas Sticht
Navy Personnel R&D Center
San Diego, CA 92152-6800

Dr. John Tangney
AFOSR/NL
Bolling AFB, DC 20332

Dr. Kikumi Tatsuoka
CERL
252 Engineering Research Lab.
Urbana, IL 61801

Technical Director, ARI
5001 Eisenhower Avenue
Alexandria, VA 22333

Dr. Perry W. Thorndyke
FMC Corp., Central Engineering Labs
1185 Coleman Avenue, Box 580
Santa Clara, CA 95052

Professor Chu Tien-Chen
Mathematics Department
National Taiwan University
Taipei, TAIWAN

Dr. Douglas Towne
Behavioral Technology Labs
1845 S. Elena Avenue
Redondo Beach, CA 90277

Dr. Kurt Van Lehn
Carnegie-Mellon University
Dept of Psych, Schenley Park
Pittsburgh, PA 15213

Dr. Beth Warren
Bolt Beranek & Newman, Inc.
50 Moulton Street
Cambridge, MA 02138

Dr. Donald Weitzman
MITRE
1820 Dolley Madison Blvd.
MacLean, VA 22102

Dr. Keith T. Wescourt
FMC Corp. Central Engineering Labs
1185 Coleman Ave. Box 580
Santa Clara, CA 95052

Dr. Douglas Wetzel
Code 12
Navy Personnel R&D Center
San Diego, CA 92152-6800

Dr. Barbara White
Bolt Beranek & Newman, Inc.
10 Moulton Street
Cambridge, MA 02238

Dr. Christopher Wickens
Department of Psychology
University of Illinois
Champaign, IL 61820

Dr. Heather Wild
Naval Air Development Center
Code 6021
Warminster, PA 18974-5000

Dr. Michael Williams
IntelliCorp
1975 El Camino Real West
Mountain View, CA 94040-2216

Dr. Robert A. Wisher
Army Inst. for the Beh. and Soc. Sci.
5001 Eisenhower Avenue
Alexandria, VA 22333

Mr. John H. Wolfe
Navy Personnel R & D Center
San Diego, CA 92152

Dr. Wallace Wulfeck, III
Navy Personnel R & D Center
San Diego, CA 92152-6800

Dr. Joe Yasatuke
AFHRL/LRT
Lowry AFB, CO 80230

Dr. Masoud Yazdani
Department of Computer Science
University of Exeter
Exeter EX4 4QL Devon, ENGLAND

Mr. Carl York
System Development Foundation
181 Lytton Avenue, Suite 210
Palo Alto, CA 94301

Dr. Joseph L. Young
Memory & Cognitive Processes
National Science Foundation
Washington, DC 20550

END
DATE
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DTIC