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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

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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.
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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 solely 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.
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, presumably 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. 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 quantities 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 processes 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. 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 learners.

**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 -- largely 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 vocabulary 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 metacognitive 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 offered. 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.
References


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

<table>
<thead>
<tr>
<th>Learner</th>
<th>Major</th>
<th>SAT (V/M)</th>
<th>Native Language</th>
<th>Self-rating learning from English</th>
<th>command of science vocab</th>
</tr>
</thead>
<tbody>
<tr>
<td>HS(^a)</td>
<td>Geology</td>
<td>NA</td>
<td>English</td>
<td>Extr. good</td>
<td>Extr. good</td>
</tr>
<tr>
<td>MR(^b)</td>
<td>Physics</td>
<td>560/650</td>
<td>English</td>
<td>Good</td>
<td>Extr. good</td>
</tr>
<tr>
<td>LH</td>
<td>Communications</td>
<td>990-both</td>
<td>English</td>
<td>Extr. good</td>
<td>Good</td>
</tr>
<tr>
<td>DW(^c)</td>
<td>Sociology</td>
<td>550/590</td>
<td>English</td>
<td>Extr. good</td>
<td>Good</td>
</tr>
<tr>
<td>II</td>
<td>Bus./econ</td>
<td>380/540</td>
<td>Croatian</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>EH</td>
<td>Bus./econ.</td>
<td>550/500</td>
<td>Dutch</td>
<td>Good</td>
<td>Extr. good</td>
</tr>
<tr>
<td>GL</td>
<td>History</td>
<td>520/440</td>
<td>Spanish</td>
<td>Extr. good</td>
<td>Good</td>
</tr>
</tbody>
</table>

\(^a\) 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

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

<table>
<thead>
<tr>
<th>Goal:</th>
<th>Delimit the search space.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Means:</td>
<td>Use the results of question encoding and/or memory search.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Goal:</th>
<th>Find information relevant to the question.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Means:</td>
<td>Global Search: Scan/skim text. This may be exhaustive or self-terminating.</td>
</tr>
<tr>
<td></td>
<td>Guided Search: Use question keywords, topic, headings, subheadings to localize search.</td>
</tr>
<tr>
<td></td>
<td>Use &quot;remembered&quot; locations to localize search.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Goal:</th>
<th>Process the text information in the context of the task defined by the question.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Means:</td>
<td>Read, Reread</td>
</tr>
<tr>
<td></td>
<td>Rephrase, Paraphrase the text and the question.</td>
</tr>
<tr>
<td></td>
<td>Summarize</td>
</tr>
<tr>
<td></td>
<td>Reason/Apply/Integrate</td>
</tr>
</tbody>
</table>
Table 5

DW's protocol for 12.6 Explanation question

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

<table>
<thead>
<tr>
<th>Search types</th>
<th>Additional processing events</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>+question analysis</td>
</tr>
<tr>
<td>A. memory search, answer retrieval</td>
<td>A.000</td>
</tr>
<tr>
<td>B. text search, answer retrieval</td>
<td>B.000</td>
</tr>
<tr>
<td>C. memory search, text search, answer retrieval</td>
<td>C.0000</td>
</tr>
<tr>
<td>D. text search (information is not &quot;in&quot; text), reason beyond text or compute answer</td>
<td>D.0000</td>
</tr>
</tbody>
</table>

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 that is given verbatim in the text (see 12,3E) may be applied.
Table 9

Strategic Solution Types

<table>
<thead>
<tr>
<th>Question Type</th>
<th>GL</th>
<th>II</th>
<th>Learners EH</th>
<th>MR</th>
<th>HS</th>
<th>LH</th>
<th>DW</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TYPE 1: Verbatim relationship between the question and the text.</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2,3A</td>
<td>B.1110¹</td>
<td>B.1001¹</td>
<td>C.0010¹</td>
<td>C.0001¹</td>
<td>A.1010⁴</td>
<td>A.0000⁴</td>
<td>C.1011¹</td>
</tr>
<tr>
<td>12,1A</td>
<td>B.0001¹</td>
<td>A.0000¹</td>
<td>A.0011¹</td>
<td>A.0001¹_{lc}</td>
<td>A.0000¹</td>
<td>A.0000¹</td>
<td>A.0001¹</td>
</tr>
<tr>
<td>12,3A</td>
<td>B.1000¹</td>
<td>B.1000¹</td>
<td>A.1000¹</td>
<td>A.0000¹</td>
<td>B.0000¹</td>
<td>B.1000¹</td>
<td>A.1001¹</td>
</tr>
<tr>
<td>12,3C&amp;D</td>
<td>B.0000¹</td>
<td>B.0000¹</td>
<td>B.0000¹</td>
<td>B.0000¹</td>
<td>B.0000¹</td>
<td>B.0000¹</td>
<td>B.0000¹</td>
</tr>
<tr>
<td>12,3E</td>
<td>B.0100¹</td>
<td>B.0100⁴</td>
<td>B.1010⁵</td>
<td>B.0100¹</td>
<td>B.0100¹</td>
<td>B.0000¹</td>
<td>A.0001¹</td>
</tr>
<tr>
<td><strong>TYPE 2: Paraphrase relationship between the question and the text.</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2,1A</td>
<td>A.0000⁴</td>
<td>A.0001⁴_{lc}</td>
<td>C.0010⁴</td>
<td>B.1010⁵</td>
<td>B.1010⁴</td>
<td>A.1001³</td>
<td>B.0011¹</td>
</tr>
<tr>
<td>2,1B</td>
<td>A.0000¹</td>
<td>B.0010⁵</td>
<td>C.0100⁴</td>
<td>B.0011¹</td>
<td>B.1010⁴</td>
<td>A.1001³</td>
<td>C.0000¹</td>
</tr>
<tr>
<td>2,5</td>
<td>B.0011¹</td>
<td>B.0000¹</td>
<td>B.1010¹</td>
<td>B.0001¹</td>
<td>A.1110³</td>
<td>B.1010³</td>
<td>B.1110³</td>
</tr>
<tr>
<td>12,2A</td>
<td>B.1010⁴</td>
<td>B.0000¹</td>
<td>B.1100⁴</td>
<td>A.0000¹</td>
<td>A.0001¹_{lc}</td>
<td>B.1100⁴</td>
<td>B.1110⁴</td>
</tr>
<tr>
<td><strong>TYPE 3: Verbatim &quot;look-up&quot; plus comparison.</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12,1B&amp;C</td>
<td>B.1100²</td>
<td>A.0101²</td>
<td>B.0000³</td>
<td>C.0100¹</td>
<td>A.0100¹</td>
<td>A.1100²</td>
<td>B.0100²</td>
</tr>
<tr>
<td>12,2B</td>
<td>B.1100⁴</td>
<td>B.0110⁴</td>
<td>B.0000⁴</td>
<td>A.0101¹</td>
<td>B.0100²</td>
<td>B.1100⁴</td>
<td>B.1110⁵</td>
</tr>
<tr>
<td>12,5</td>
<td>B.0001¹</td>
<td>C.1011¹</td>
<td>A.0001¹</td>
<td>A.0000³</td>
<td>A.0000¹</td>
<td>A.0000⁴</td>
<td>A.0001¹_{lc}</td>
</tr>
</tbody>
</table>
**TYPE 4: Cross paragraph integration (verbalim 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(lc) |
| 12,4 | B.0001^1 | A.0000^1 | B.0000^1 | A.0000^1 | A.0001^1 | A.0001^1(lc) | C.1010^1 |
| 12,6 | B.1001^1 | A.0000^1 | B.0000^1 | A.0000^1 | B.1010^1 | A.0001^1(lc) | C.1011^3 |

**TYPE 5: Reasoning, application, computation.**

| 2,2  | A.0001^2(lc) | 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 |

^aSuperscript 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. (lc) 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<sup>a</sup>

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

<sup>a</sup>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.

<sup>b</sup>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\textsuperscript{a}

<table>
<thead>
<tr>
<th>Learners</th>
<th>Native English</th>
<th>Nonnative English</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MR</td>
<td>HS</td>
</tr>
<tr>
<td>Correct</td>
<td>16</td>
<td>12</td>
</tr>
<tr>
<td>(89%)</td>
<td>(67%)</td>
<td>(67%)</td>
</tr>
<tr>
<td>Search Type</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Memory</td>
<td>9 (8)</td>
<td>10 (7)</td>
</tr>
<tr>
<td>Text</td>
<td>5 (4)</td>
<td>7 (5)</td>
</tr>
<tr>
<td>Both</td>
<td>3 (3)</td>
<td>---</td>
</tr>
<tr>
<td>Compute</td>
<td>1 (1)</td>
<td>1 (0)</td>
</tr>
<tr>
<td>Added Processing Events</td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>Question analysis</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Reasoning/inference</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Monitoring\textsuperscript{b}</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>Process</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>Product</td>
<td>8</td>
<td>3</td>
</tr>
</tbody>
</table>

\textsuperscript{a}Maximum = 18. Frequencies in parentheses are the frequencies of correct solutions.

\textsuperscript{b}These data are the number of solutions containing either process or product monitoring.
Table 12

Summary profiles of the seven oceanography learners

<table>
<thead>
<tr>
<th></th>
<th>Accuracy</th>
<th>Knowledge</th>
<th>Speed of solution</th>
<th>Monitoring</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Successful learners</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MR</td>
<td>High</td>
<td>Expert</td>
<td>Quick</td>
<td>Moderate</td>
</tr>
<tr>
<td></td>
<td>(89%)</td>
<td></td>
<td>(67 events)</td>
<td>(27 events)</td>
</tr>
<tr>
<td>GL&lt;sup&gt;a&lt;/sup&gt;</td>
<td>High</td>
<td>High</td>
<td>Slow</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>(83%)</td>
<td></td>
<td>(148 events)</td>
<td>(46 events)</td>
</tr>
<tr>
<td><strong>Moderately successful learners</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HS</td>
<td>Moderate</td>
<td>Expert</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>(67%)</td>
<td></td>
<td>(92 events)</td>
<td>(31 events)</td>
</tr>
<tr>
<td>DW</td>
<td>Moderate</td>
<td>Low</td>
<td>Slow</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>(67%)</td>
<td></td>
<td>(172 events)</td>
<td>(76 events)</td>
</tr>
<tr>
<td><strong>Less successful learners</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>J&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Low</td>
<td>Medium</td>
<td>Quick</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>(55%)</td>
<td></td>
<td>(90 events)</td>
<td>(17 events)</td>
</tr>
<tr>
<td>EH&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Low</td>
<td>Low</td>
<td>Quick</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>(55%)</td>
<td></td>
<td>(83 events)</td>
<td>(32 events)</td>
</tr>
<tr>
<td>LH</td>
<td>Low</td>
<td>Low</td>
<td>Quick</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>(44%)</td>
<td></td>
<td>(80 events)</td>
<td>(9 events)</td>
</tr>
</tbody>
</table>

<sup>a</sup>Nonnative English speakers
Appendix A: Texts, questions and answers used in the study.
TABLE 2.1 Variation of Gravitational Acceleration with Altitude above Sea Level

<table>
<thead>
<tr>
<th>Altitude (km)</th>
<th>Acceleration (m/s²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>9.806</td>
</tr>
<tr>
<td>10</td>
<td>9.776</td>
</tr>
<tr>
<td>100</td>
<td>9.600</td>
</tr>
<tr>
<td>1000</td>
<td>7.415</td>
</tr>
<tr>
<td>10,000</td>
<td>5.447</td>
</tr>
<tr>
<td>100,000</td>
<td>9.036</td>
</tr>
</tbody>
</table>

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 mass 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.

Of course, just one measurement with one gravimeter 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-
Seismographs record echoes of the original seismic disturbance because seismic waves reflect from subsurface interfaces. Later echoes come from greater depths.

Seismic waves have two properties that make them extremely fruitful in revealing internal earth structure. One is that some of them are reflected when passing through a media 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 running a seismograph above a 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 can 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. In analogy, when the wheels on 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 changes gradually and continuously. 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 travelling through the earth can be put into two categories (Figure 2.12). Those whose vibrations are parallel to the direction...
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.

![Diagram of seismic waves](image)

**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.

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.

![Diagram of waves in a spring](image)

**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.

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 push 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 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 further. 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).

![Diagram of P-waves and S-waves](image)

**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.

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-
Compared to other terrestrial planets, the earth’s climate is extremely
wild. 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 thicknesses
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 behavior is 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 HYDROSHERE

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 3% of the water is stored in
groundwater and only a trace (0.04%) 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 rainfall, 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 var-
inous reservoirs is to imagine that we could make the earth’s surface per-
fetly 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.
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 12.1]. At room temperature (about 20°C) the atmosphere can be up to 2.21% water vapor. There are several terms dealing with the water content of air. We call air "saturated" if it is hold-

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 Eyring Depths

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<th>Reservoir</th>
<th>Percent of Total</th>
<th>Eyring Depth (m)</th>
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<tr>
<td>Oceans</td>
<td>97.96</td>
<td>2685</td>
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<tr>
<td>Polar caps and ice</td>
<td>1.84</td>
<td>68</td>
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<tr>
<td>Ground water</td>
<td>0.36</td>
<td>10</td>
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<tr>
<td>Rivers and lakes</td>
<td>0.04</td>
<td>1</td>
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<td>Atmosphere</td>
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<td>0.02</td>
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FIGURE 12.1 Hydrologic cycle, depicting some of the major mechanisms for the transfer of water between reservoirs.

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 640 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 skin, cooling us off.

From a microscopic point of view, the following happens when water evaporates. Temperature is a measure of the average kinetic energy 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 are "evaporated." At higher temperatures, more will be moving fast enough to evaporate, so the water evaporates faster at higher temperatures.

*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°C to 21°C as when the temperature changes from 10°C 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).

§ 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 proportion 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 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 \( G \)s 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 distribution" 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 surface topography, not subsurface masses. "Using altimeters" or "with altimeters" is an incorrect answer by itself. In combination with a discussion of gravity and effects 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 to 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) 0.9% (.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" and "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).
(S9 - 14 explains process underlying molecule movement.)
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.

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