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ABSTRACT

In order to study why students have difficulty learning from science textbooks, this study investigated how middle school students use textbooks and how their thinking about one science concept (photosyntheis) was influenced by the reading of three different science texts. One of the texts used was an experimental one written to challenge and change students' common misconceptions about how plants get their food. The other two texts were commercially available texts covering the same content as the experimental text. Daily interviews were used to trace the thinking of students (N=18) as they read one text chapter over a 3-day period. This approach provided detailed information about the cognitive lives of students during textbook reading that has important implications for understanding learning processes, teaching, and textbook development. A uniqu ; part of the study was the exploration of conceptual learning from text. Findings, among others, show that both "good" a. ; "poor" readers have difficulty learning from text because they us('neffective text processing strategies and that only studen ;ng a conceptual change strategy for processing text were succes in giving up or modifying their incorrect prior knowledge in favo: or text explanations. (JN)

CONCEPTUAL CHANGE LEARNING AND STUDENT PROCESSING OF SCIENCE TEXTS

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Conceptual Change Learning
and Student Processing of Science Texts

Overview of the Study

In order to explore why students have difficulty learning from science textbooks, this study investigated how middle school students use textbooks and how students' thinking about one science concept, photosynthesis, was influenced by the reading of three different science texts. One of the texts used in the study was an experimental one written to challenge and change students' common misconceptions about how plants get their food. The other two texts were commercially available texts covering the same content as the experimental text.

The study used daily interviews to trace the thinking of a small group of students (18) as they read one text chapter over a 3-day period. This approach provided detailed information about the cognitive lives of students during textbook reading that has important implications for understanding learning processes, for teaching, and for textbook development.

A unique feature of this study is the exploration of conceptual change learning from text. How this type of learning is different from the kind of learning typically assessed in studies of reading comprehension is described in the next section.

Conceptual Change Learning vs. Comprehension

I: What is photosynthesis?

Kevin: Well, in the leaves, in the green plants, they have little chloroplasts which inside that have chlorophyll. When the sun shines on it does photosynthesis which changes, well it doesn't really change, but the plant has certain chemicals that change the sunlight. . . Well, they have certain chemicals that the sunlight changes into food which is energy for the plant.

This eighth grade student read a text chapter about photosynthesis and than gave this explanation of the process. Has he successfully learned about photosynthesis? Most teachers would be satisfied that he had. That he was able to put the definition given in the text into his own words certainly suggests that he has processed and made sense of the concept.

However, this student was also asked a different, but closely related question:

I: How does this plant get its food? (Interviewer points to a plant on the table).

Kevin: Well, <u>which</u> food?

I: You tell me.

Kevin: It gets minerals from the soil and water from the soil. It gets sunlight from the sun. It gets. . . that's about it. Besides carbon dioxide in the air.

If Kevin really understood what the text had been saying about photosynthesis, he would have answered the question by explaining that plants get their food by making it during the process of photosynthesis. Instead of talking about photosynthesis, however, he inaccurately made reference to a number of external sources of food for plants. These ideas were definitely not in the text - where did they come from?

<u>Using research on science learning to understand Kevin's learning difficulties</u>. Recent research from studies of science learning have shown that before children study science in school, they have already constructed their own "theories" to explain phenomena. These naive theories, or misconceptions, play a crucial role in students' understanding of the world

(Erickson, 1979; Nussbaum & Novak, 1976; Shayer & Wylam, 1981). These misconceptions are based on children's sensory experiences, on everyday language, and on prior school learning. They are difficult for children to relinquish, even after instruction (Champagne & Klopfer, 1980; LeBoutet Barrell, 1976). In a study of student learning after activity-based instruction about photosynthesis, for example, only 11% of 220 fifth graders ended an 8-week unit of experiments and discussions understanding that plants get their food by making it. Instead, like Kevin, they continued to cling to the incorrect notions that they held prior to instruction - that plants take in their food from outside sources and that plants have multiple sources of food (Roth, Smith, and Anderson, 1983).

For students entering instruction holding these alternative theories, meaningful learning will not result if new knowledge is simply added into memory. According to schema theory, meaningful learning cannot occur unless new knowledge is appropriately linked to prior knowledge. But students like Kevin are faced with a tremendous task in making these links appropriately They must first recognize that the new concept, in this case photosynthesis, is related to notions they hold about plants and plants' need for food. They must link new information not only to prior knowledge that is consistent with the scientific notions but also to incompatible prior knowledge. Then they must realize that their own notions are at least partially in conflict with the scientific explanation. They must also come to recognize that their own ideas are faulty or incomplete, and they must be made aware that the scientific explanation provides a more convincing and powerful alternative to their own notions.

Thus, learning for these students is not simply a matter of linking new ideas to already existing prior knowledge, or schema. In addition to linking, or assimilating, new ideas to old, these students have to change their old beliefs. For this reason, Posner et al. (1982) have called this kind of learning conceptual change.

This kind of learning demands more than the kind of comprehension usually assessed on standardized or teacher-made tests. Kevin, for example, could answer the question, "What is photosynthesis?" Thus, he comprehended the text explanation of photosyntesis. However, he did not change his personal, incorrect theories about how plants get their food.

Is it possible for more students to experience meaningful conceptual change learning or must such learning come only with much greater maturity and only to the elite few who seem more naturally inclined toward scientific ways of thinking? In order to improve science instruction so that this difficult conceptual change learning is possible for more students, Posner et al. (1982) have proposed a model for conceptual change instruction. They suggest four conditions that must be fulfilled if students are likely to make changes in their central concepts:

1. There must be dissatisfaction with existing conceptions. Students must be aware of their own conceptions and recognize the dissonance between their own ideas and those shared by the scientific community.

2. A new conception must be intelligible. The student must know what the idea means and be able to construct a representation of it. This does not mean the student must believe it to be true or related to the real world.

3. A new conception has to be initially plausible. The student must find the new conception to be potentially true and believable, consistent with his or her existing view of the world. That is, the student must be able to reconcile the new conception with his or her prior conceptions.

4. A new conception has to be fruitful. If a student is going to incorporate a new conception into his or her schema at the expense of a very comfortable, long-held misconception, there has to be a convincing reason. Thus, the new conception has to be shown to be more useful than the old conception. A new conception can be viewed as fruitful it if can solve a previously unsolved problem, if it suggests new ideas, or if it gives better explanatory and predictive power than was previously possible.

The text Kevin read did not help Kevin fulfill Posner's four conditions. Like most science textbooks it focused only on making the concept of photosynthesis intelligible. The text did not help him recognize that the new concept was in conflict with his prior notions. As a result, Kevin never saw the need to reconcile the new information with his prior assumptions that plants get food from the soil and other sources. Since Kevin did not understand that photosynthesis is the plant's only source of food, it is doubtful he would be able to apply this idea to understand other key biological concepts such as the unique role plants play as food producers in ecosystems.

Many studies of reading comprehension have shown how rich prior knowledge (or schemata) facilitates and makes possible learning from text (Anderson, R.C., 1977; Bransford & McCarrell, 1973; Anderson, Spiro & Anderson, 1978; Meyer, 1984; Frederikson, 1975; Pearson, Hanson, & Gordon, 1970). These studies have focused, however, on prior knowledge that is rich and compatible with the text content. What about students like Kevin who have "rich" prior knowledge that conflicts with the text content? A few studies have explored how schema-driven interpretations of text can have costs as well as benefits in learning from text (Thorndyke and Hayes-Roth, 1979). In this vein, Spiro (1979), Maria and MacGinitie (1982), and Lipson (1983), have shown that prior knowledge can interfere with comprehension of text. It seems reasonable that this is what happened to Kevin. However, the reading research has not explored learning from text in a way that explains why Kevin could comprehend the text explanation of photosynthesis without learning that this explanation is about how real-world plants get their food.

Schema-based reading research, including the studies on incompatible prior knowledge, has focused on understanding how the reader's prior knowledge shapes the interpretation of text in a one-way view:

Reader's Schema $\longrightarrow$ Text

These researchers have been interested in readers' comprehension of text, but they have not looked at conceptual change learning from text. In order to understand whether and how students develop meaningful conceptual change learning from text, it is necessary to also look at the reverse direction: How does the text change a student's existing schemata?:

Reader's schema $\rightleftarrows$ text

This study extends the reading research done to date by investigating this critical question.

Research Questions

What does it take for students to undergo conceptual change learning from reading science text? What would have helped Kevin recognize the dissonance between his two answers quoted above? Why do so many students fail to undergo conceptual change learning from text? It is the hypothesis of this study that an experimental text that explicitly addresses students' common misconceptions and that is structured to help students fulfill Posner's four conditions would be more successful in helping students undergo conceptual change learning than traditional science texts that focus only on making new conceptions intelligible.

The overall objective of this study was to explore students' cognitive processing of three different textbooks, all covering the concept of photosynthesis, in order to identify both the effective and ineffective strategies students used to process texts and to identify the features of text that influenced students' selection of a text-processing strategy. The specific research objectives were:

1. To identify the cognitive reading strategies used by 18 middle school students while reading a chapter about photosynthesis in one of two traditional science texts or in an experimental text designed to address students' misconceptions.

2. To compare the way content organization in the two traditional texts and in the experimental text influenced students' strategy selection.

3. To compare the effectiveness of the two traditional texts and the experimental text in terms of students' conceptual change learning.

Methods

Procedures

The study focused on student processing of sustained passages of three different student texts, each about 20 pages, or 3400 words, in length. The study did not include any teacher instruction. This permitted comparisons between student processing of the experimental text to student processing of traditional texts without the confounding variables of the classroom.

To study the ability of the text to induce significant conceptual changes in students and to maintain some context validity, each student read one complete text chapter over three days. In this way, students were able to read one text over a period of time similar to what whould be typical in classroom situations. A stratified random sampling procedure was used to assign 18 middle school students to groups (n= 6 for each text) so that each group consisted of students reading above, at, and below grade level according to Metropolitan achievement test results.

Interviews. Each day the student read a section of the assigned text and was interviewed immediately afterwards. Interview protocols were designed to trace what students were thinking as they read the texts. Two parts of students' thinking were of particular interest: What strategies did students use to make sense of the text? How did students' ideas about photosynthesis and food for plants change after each days reading? Theinterviews were designed to reveal how characteristics of the texts and how characteristics of students' prior knowledge were causing students' notions about photosynthesis and food for plants to change. To address these questions and objectives, the interview protocol combined questioning strategies typically used by reading researchers studying students' comprehension and strategies used by researchers studying students' conceptions of science topics. There were three basic parts to each interview, with each part representing a different approach to exploring student thinking.

The first section of the interview asked the students to recall whatever they could remember having read about in the text that day. After the recall, students were asked to give one or two main idea statements about the text. The second part of the interview had a clinical interview format. This series of questions was designed to explore how students' real-world thinking was being influenced by the text. Thus, while the first part of the interview was very text-based, in this section of the interview students were encouraged to use both text knowledge and personal, experiential knowledge. The last section of the interview focused on understanding how students used the texts. A variety of questions were designed to stimulate students' recall of what strategies they used while reading the text. For example, the interviewer went back over the questions posed in each text and asked students how they had arrived at their answers to them. The purpose of this was to stimulate students' memory of how they used text/prior knowledge to answer the questions and what strategies they used to answer them.

Interviews were audio-recorded and later transcribed.

Pre- and Posttests. Pretests were given two weeks prior to the study to assess prior knowledge, and identical posttests were given the day after the last reading session. The test elicited information about students' misconceptions as well as information about the goal concepts in each of the texts. In addition, it contained multiple items exploring the same concept. These items were in a variety of formats -- true/false, multiple choice, checklists, and open response questions requiring students to write out answers. Some test items took a form commonly used in clinical interviews: students were asked to make a choice or prediction, then to explain or justify their choice.

The research design is summarized in Figure 1.

figure 1

Materials

Experimental Text. In designing a text to address students' misconceptions about food for plants (Roth, 1985), two sources of information not normally available to textbook writers were used:

1. A detailed knowledge of middle grade students' misconceptions about photosynthesis and food for plants (Roth, Smith, and Anderson, 1983).

2. A documentation of difficulties encountered by students receiving instruction about photosynthesis from the Science Curriculum Improvement Study (SCIIS) curriculum (Smith, 1983; Smith & Anderson, 1984; Anderson & Smith, 1983c; Roth, Smith & Anderson, 1983).

The text incorporates the experiments used in SCIIS curiculum unit (Knott et al., 1978), but these experiments are framed with Posner's model of conceptual change instruction. Thus the text first elicits students' misconceptions by asking students to answer questions like, "How do you think plants get their food?" or "How would you define food?" The text then presents both experimental evidence and narrative text information to challenge students' common misconceptions and to convince them that certain substances they commonly describe as food for plants are not food in a scientific sense. This sets students up to be ready to find the text explanation of photosynthesis intelligible and plausible: If water, soil, fertilizer, and sun are not food for plants, then what is?

Thus, only after all of the students' usual ways of describing food for plants have been ruled out does the text provide an explanation of the scientific concept of photosynthesis. Finally, the text provides reviews of key concepts and numerous application questions that require students to apply new concepts to a variety of situations in which they must contradict their own misconceptions.

The experimental text was submitted to a content analysis to identify the number and kinds of goal concepts that were presented and to document the misconceptions that were addressed. This analysis provided a general overview of the content coverage, a more detailed definition of the relative emphasis given to different conceptions, and a description of the pattern of emphasis that students would encounter over the three days of reading. This analysis identified the total number of idea units for each day's reading, the number of idea units addressing the defined goal concepts each day, and the number of idea units addressing misconceptions each day.

Three readability formulae were used as a measure of vocabulary level and sentence complexity of the experimental text. Using the SMOG (McLaughlin, 1969), Fry (1977), and Raygor (1977) schemes, readability scores representing appropriate grade levels for the text were 9, 5, and 6, respectively.

Selection of two commercially available texts. A number of commercially available science texts were submitted to the same content and readability analyses as the experimental text. This information was used to select two commercially available texts that matched the experimental text as closely as possible in terms of content coverage and emphasis, readablity level, and length. The two texts selected were Concepts in Science, Brown (Brandwein et al., 1980) and Modern Science, Level Six (Smith, Blecha, and Pless, 1974).

Data Analysis Procedures

Identifying reading strategies. The data provided several sources of information about each student's thinking. These were the written pre- and posttests, the written answers to questions posed in the textbook, and the students' responses to a number of different types of questions during the three interviews.

In order to identify the strategies students used while reading, these data sources were first analyzed to trace how each student's thinking about food for plants had changed over the five day period. Next, comparisons between the text content each day and each student's recall were made. This comparison permitted the identification of instances where the student a) recalled text ideas accurately, b) distorted ideas in text, c) recalled ideas that were not in text at all, and d) failed to recall ideas from text. Students' answers to other interview questions received a similar analysis in an attempt to identify when a student was drawing from text information and when a student was relying on prior knowledge.

Drawing from these analyses, hypotheses were made about student's reading strategies. A case study of each student was written, and during this process, the hypothesized strategies were supported and refined.

Identifying text features that infuenced strategy selection. Once the students' reading strategies had been identified, it was possible to go back to the data in order to explain how the content organization of each text influenced students' selection of a strategy. Drawing from the data analysis of individual case studies reported above, any evidence of similar patterns of student thinking among students using a particular text were sought. If students reading the same text were found to use similar strategies that were different from studen[illegible]ding another text, this would provide evidence that text content organiz[illegible]made a difference in students' strategy selection. Comparisons were also made between students' strategy switches and the content of the particular text in order to develop explanations for how the text may have influenced students' strategy switches.

Comparing the effectiveness of the three texts in terms of conceptual change learning. The case study analysis provided descriptive evidence of how students' thinking about photosynthesis and food for plants changed over a five day period. This qualitative analysis provided one source of evidence of differences in student learning among the three groups.

Additional information about student learning came from analysis of the pre- and posttest data. Test data were used to generate descriptions of students' beliefs rather than to produce summative scores of how much students knew. The test data were analyzed to generate a series of conception scores that reflected the strength of each student's belief in four goal conceptions and four common misconceptions. The conception scores were developed by using an explicit series of algorithms to make inferences from the test about students' belief systems. Evidence from a number of test items was used to generate each conception score, with some evidence being weighted more heavily than others.

The conception scores were used to make comparisons among the three groups. For example, the percentage of students in each group who ended instruction believing that plants take in their food could be compared.

Results and Discussion

Reading Strategies

Analysis of each student's complete data package focused first on identification of the text processing strategies that students used. Definite differences in text processing strategies were identified, and analysis of these differences led to the difinition of six different strategies.

All of the strategies used by the students were described in terms of how students drew from three different sources of knowledge: a) disciplinary (or text) knowledge, b) real-world (or experiential) knowledge related to the subject matter, and c) real-world knowledge about how to get along in school

(school knowledge). Disciplinary knowledge is defined as the conceptually, organized, formal understanding of a discipline (such as biology). Since disciplinary knowledge is what teachers and textbooks usually have as their goal, it will also be referred to as text knowledge. Real-world knowledge, in contrast, is commonsense knowledge accumulated over time in a non-analytical, often nonverbal way. It makes sense to the individual in spite of its inconsistencies, and it is used to spontaneously explain real-world events. This type of experiential knowledge is what science educators have studied as naive theories, misconceptions, or incorrect prior knowledge. Meaningful conceptual change learning occurs when these first two worlds of knowledge are appropriately integrated. However, another kind of real-world knowledge - knowledge about how classrooms, textbooks, and schools work - can enable a student to get by <u>without</u> developing meaningful understandings of disciplinary knowledge. This school knowledge includes the facts, algorithms, or strategies used to pass tests and perform adequately in school. Thus, students have prior knowledge about the schooling process itself (about teachers, textbooks, learning) that plays an important role in their processing of science text.

The six different ways students drew from these three sources of knowledge are described next. These strategies are summarized in Table 1. Full case studies of the strategies-in-use are available elsewhere (Roth, 1985).

Table 1 goes here

1. Overreliance on prior knowledge in order to complete a school task. Students using this strategy interpreted the text almost completely in terms of their incorrect real-world knowledge about plants and food. When asked to recall what the text said, for example, they frequently attributed the text with having said things that were not in the text but came from their prior knowledge. Although they reported the text made sense to them, these students appeared to avoid thinking about the text itself as much as possible. If they could decode the words and get enough of the gist of the text to call up an appropriate and well-developed real-world schema, the text "made sense."

For example, Maria read a section of the Concepts in Science text that used milk as an example of how all foods can ultimately be traced back to green plants, the food producers. Maria announced that "most of this stuff I already knew," and that this was the easiest section to understand. "It was about milk." When probed, she expanded her summary of the "text": "It's just about milk... how we get our milk from cows." She never picked up any notion that plants make food. This is typical of her pattern of reading to find familiar ideas, ignoring the rest of the text, and relying on prior knowledge to fill in the details.

The students using this strategy answered questions posed in the text by thinking about their real-world knowledge about plants rather than using text knowledge. Without thinking about plants' roles in producing food, for example, Maria came up with the right answer to the following question by thinking about her prior knowledge:

Question: All the foods we eat can be traced finally back to the
a) green plants
b) cows

Maria: Correctly picked "a" and explained: I don't know... I just circled green plants because everybody eats... not everybody eats cows but everybody eats green plants.

Thus, the text "made sense" if students had a source of information (prior knowledge) to answer the questions in the text and in the interview. Performance of the assigned task and compliance with school expectations was the reading goal of these students.

This strategy is similar to a group of poor readers identified by Spiro (1979) and Maria and MacGinitie (1982). In their studies they referred to these readers as overrelying on "top down" processing of text.

2. Overreliance on words in the text in order to complete a school task. Like another group of poor readers studied by Spiro (1979), these students were "bottom up" processors of text who focused on the details in the text and failed to make any sense of the meaning of the text. The details were just isolated words that had no relationship to each other or to any prior real-world knowledge. In their recalls, these students identified words or phrases ("It was about chlor-something and a ecosystem.") without giving any description or meaning to them. In spite of this lack of attention to meaning, these students felt they understood the text if they were able to decode the words and to identify details in the text that satisfactorily answered questions posed by the text. They were only confused when they encountered vocabulary words that they could not decode. For example, when asked whether there were any places that the Modern Science text was confusing, Tracey reported on Day 2 that it was just "some of the words I didn't get." On Day 3, she pointed out the following words as places where she was confused: germination, chlorophyll, chloroplast, cotyledon, embryo, dormant.

That this strategy of focusing on words in the text was never used to make sense of the text became clear when students were asked questions. In answering text-posed questions, they simply looked for a "big" word in the question, located that word in the text, and copied the word along with words surrounding it in the text. These copied words may or may not have sensibly answered the question, but the students were satisfied just to have an answer. Frequently, this strategy produced answers that would be acceptable to most teachers. When students were asked interview questions about real-world plants, students relied totally on their experience-based knowledge. No relationship was seen between the text and this real-world knowledge. Thus, Tracey recalled the book being about "chlorophyll" and "photosynthesis," but these words were never mentioned when she was asked about how a particular plant gets its food.

The use of text by these students was driven by their school knowledge of what was needed to finish the work. From prior successes in school they found that being able to recite key words and phrases from the text (especially large vocabulary words) can often get you by. Real-world knowledge was a completely separate realm of knowledge used to explain everyday, non-text phenomena.

3. Overreliance on unrelated facts in the text due to an addition notion of learning. This strategy was used by better readers who had higher goals for their reading than just finishing the assigned work. These students held the view that school science learning is all about developing a list of facts about natural phenomena. This list of facts is what you are supposed to be learning about in school. Their prior experiences with schooling had convinced them that memorization of unrelated facts is satisfactory learning.

Thus, they never attempted to relate the facts from the text to each other or to their real-world knowledge about plants.

While students using strategy 2 tended to recall single words which they listed without reference to any meaning, students with the additive notion of learning as their goal often had fairly accurate and complete recalls of explicit text material. They might recall, for example, that "plants make their food" and that "chlorophyll is what makes leaves green." However, they remembered ideas in no particular conceptual order, they placed equal emphasis on trivial details and on main concepts, and they did not link facts together to develop an overall picture of the main concepts. For example, Myra remembered a lot of details about an experiment that had been described in the Concepts in Science text:

Myra's Recall: She had some fish and she had some plants in there and one day she was looking at them and a bubble came out of one of the plants. And she started experimenting a little, and she noticed they were giving off oxygen...They asked us what we think about is she trying - is it oxygen, they asked us what we thought. I put one time it did and one time it didn't...They said the first time it wasn't sunny all the time. The first time it was out for 1 week and everyday it was sunny.

However, when the interviewer asked Myra about whether the girl doing the experiment had made a conclusion about the role of the sun, Myra said simply, "no." Although she remembered a lot of details, she missed the critical reason that the experiment was included in the text.

Like students using strategies 1 and 2, students using this strategy answered questions about real plants without making reference to any of the facts they had read about in the text and included in their recall. Use of this additive notion of learning prevented students from linking text information to real plants. It also prevented students from making sense of the disciplinary understanding of photosynthesis.

Students using this strategy and the first two strategies were unable to make sense of the text explanation of photosynthesis. Since the text view was not intelligible to them, it was impossible for them to use that text view to change their misconceptions about food for plants. Posner's second criterion for conceptual change had not been met.

4. Separation of disciplinary knowledge and real-world knowledge in order for each to make sense. For this group of students the text explanation was intelligible. However, this disciplinary view of food for plants was not seen as having anything to do with students' equally well-ordered real-world schema of food for plants. Thus, these students had two fairly well-developed schemata of food for plants. They drew on the disciplinary schema to answer textbook questions, and they used their real-world schema to answer questions about real plants. They were unaware that they two views were in conflict with each other, and their success in school using such a strategy probably reinforced their use of the strategy.

Unlike students using strategy 3 students using this strategy did not accumulate lists of isolated facts from reading the text. They were able to conceptually organize ideas presented in text, appropriately emphasizing major ideas over minor details. Recalls for these students tended to be accurate and fairly complete with main ideas of the text appropriately identified. However, these ideas in the recall were rarely used in answering questions like, "How does this particular plant get its food?" In fact the students using this strategy often said one thing in the recall portion of the interview (such as "water is not a food") and then contradicted themselves when talking about a real-world situation ("water is food for this plant"). It is interesting to note that this is the first strategy described in which students engaged disciplinary knowledge and found it intelligible in spite of the general expectation that this is the main function of textbook reading.

5. Overreliance on prior knowledge in order to make sense of disciplinary/text knowledge. This strategy was used by a relatively large number of students, most of whom were reading at or above grade level as measured by standardized achievement tests. These students generally expected the text to confirm their prior knowledge, so that their goal in reading the text was basically to verify what they already knew. This attitude was expressed by some as, "Basically, I already knew all this."

These students did not focus primarily on developing strategies to get by in school. Instead, they seemed to be genuinely trying to make sense of the text and disciplinary knowledge, but in order for the text to make sense for them it had to fit into their real-world schema of food for plants. Thus, this is a sophisticated strategy in which readers attempted to link prior knowledge and text knowledge. This is in contrast with strategy 4 in which disciplinary knowledge was kept separate from real-world knowledge. However, because the students' real-world knowledge was so strongly held and because it was often in conflict with the content of the text, the students using this fifth strategy had to distort or ignore some of the text information to make it fit. Thus, these students did make some attempts at integrating real-world and disciplinary knowledge. However, with prior knowledge taking the driver's seat in the process, learning was often quite different from what was intended by the authors of the text.

6. Conceptual change strategy. In contrast to strategy 5, students using the conceptual change strategy allowed text knowledge to take the driver's seat in their attempts to integrate real-world knowledge and text knowledge. Thus, they used text knowledge to change their real-world ideas about food for plants.

These students were reading to make sense of what the text had to say and to apply this knowledge to their real-world thinking and misconceptions about plants. They recognized the conflicts between what the text was saying and their own naive theories, and this confict was resolved by abandoning or changing their misconceptions in favor of the more powerful, sensible disciplinary explanation.

All of the students using this strategy did things as they read the texts that were not seen among the other students. The students using this strategy were:

1) Aware of key statements in the text that were incompatible with their prior knowledge.

2) Able to recognize the main goal concepts of the text.

3) Aware of the conflict between text explanations and their misconceptions and willing to abandon misconceptions to resolve the conflict.

4) Aware that text was leading to changes in their own thinking about real-world knowledge.

5) Aware of places where the text explanations were confusing because they were in conflict with the students' previous beliefs.

6) Able to use text ideas to explain real-world phenomena.

The conceptual change strategy was the only strategy in which students made sense of the disciplinary concepts in a meaningful way. All of the other strategies enabled students to read without appropriately recognizing differences between the text's view of how plants get their food and students' own naive views. Thus, the first five strategies were not effective in terms of conceptual change learning. Although these strategies failed to be effective in terms of student learning, they were effective in helping students complete school reading tasks satisfactorily.

Text Features and Students'

Strategy Selection

The particular reading strategy used by students was determined by an interaction between characteristics of the student and characterstics of the text. To some extent students' selection of strategies was determined by individual student differences in reading ability (see Table 2). Thus, the students reading at or below grade level (as measured by standardized reading tests) appeared to only have the first three strategies in their repertoire. Only the "better" readers had the more sophisticated strategies (4 & 5) available to them.

Table 2 goes about here

However, this pattern does not hold true for the conceptual change strategy, and here is where the text influence on strategy selection becomes evident. Strategy 6, the only truly effective strategy, was used by six of the seven students reading the experimental text. One of the twelve students reading the two commercial texts used this strategy.

In addition, students reading the experimental text were almost the only ones who switched from one of the five ineffective strategies on Day 1 to the more effective conceptual change strategy on Days 2 & 3. All but one student reading the other texts either persistently used one of the five ineffective strategies or switched back and forth among alternative ineffective strategies. This data strongly suggest that text features influenced strategy selection.

The data provided many sources of information about the influence of text on strategy selection. In this section, the effects of text content organization and of text-posed questions on students' strategy selection will be described to show examples of ways text features influenced strategy selection. Case studies of three students, each reading a different text, will be presented.

Parker's reading of Concepts in Science. Parker began instruction holding some experientially-based inaccurate knowledge and some inaccurate disciplinary knowledge about photosynthesis. Using strategy 5 he tried to fit everything in the text into both a) his real-world misconceptions that plants' food is what they take in from external sources and that "food" is whatever plants need to survive and his b) disciplinary knowledge that plants produce oxygen during a process called photosynthesis. He had the inaccurate understanding that plants produce oxygen for the purpose of helping out animals. He did not see oxygen production as a by-product of the food-making process.

Apparently anticipating that students might have some knowledge about plants' production of oxygen and hoping to build on this prior knowledge, the Concepts in Science text begins with a discussion of oxygen production during photosynthesis. This is then used as a lead-in to the idea that plants also produce food during photosynthesis.

How did Parker interpret this section of the text? First of all, the discussion of oxygen production immediately suggested to him that this chapter was about things he already knew, thus suggesting or reinforcing the selection of the strategy of overrelying on prior knowledge. He repeatedly talked about how he was not learning anything new, just reviewing or adding details, and that this was easy stuff for him, "cut and dried." Throughout his reading of the text chapter, Parker focused on the oxygen production issue and largely ignored the more central issue of food production. When he did mention food production, it was always treated as less important than the oxygen production. For example, when looking back over the text at the end of the second interview, he said:

> I wasn't so much aware of the sugar as I was of the oxygen. I wasn't so aware that it was, I mean, the article makes it such a <u>stress</u>. Most of what I had studied had done, oxygen was stressed. Plants <u>do</u> make oxygen.

On Day 3 he defined photosynthesis as "the plant's way of taking carbon dioxide gas and converting it to oxygen." Not only did he fail to incorporate any notion of food production into his idea of photosynthesis, he also held the mistaken notion that carbon dioxide is changed directly into oxygen during photosynthesis.

Thus, the text's presentation of oxygen production before food production did not help Parker develop a better understanding of photosynthesis. Rather, it reinforced his use of an ineffective text-processing strategy and failed to impress on him that food production is of central importance in photosynthesis. This is particularly remarkable since this text built in a lot of redundancy into the narrative and into the questions. Parker even commented that the authors seemed to be trying to "pound the idea into our heads" by frequent repetition of the idea that plants produce food during photosynthesis.

There were other places, too, where the text organization made it easy for Parker to assimilate text ideas into his faulty prior knowledge. For example, text explanations fed right into his misconception that the reason plants produce oxygen is for the benefit of animals. The text explained carefully how oxygen given off by water plants is used by fish. In contrast, when the text explained photosynthesis in terms of hydrogen, carbon, and oxygen atoms rearranging to form sugar, it never mentioned that oxygen atoms are released as part of this process. In fact, Parker used the text to elaborate and expand this misconception. He developed the notion that plants also make food only for animals:

> Q: What is the plants' food?
> P: The plant creates glucose and it lives off minerals, sunlight, and carbon dioxide.

The section immediately following the presentation of photosynthesis in the text discusses the importance of photosynthesis for all organisms in the ecosystem, thus again reinforcing Parker's conceptualization that the food is produced for animals, not plants, to use.

The questions posed by the text were all literal level, factual recall questions that Parker could easily answer using his overreliance on prior knowledge strategy. They were almost all in an easy, 2-choice multiple-choice format. Only one question in the text suggested to Parker that his notions about food for plants might be in conflict with the disciplinary view of photosynthesis. In spite of total confidence that he understood everything perfectly, Parker did have some doubt about this question. However, he passed off this doubt as the result of an unclear question rather than his own conceptual difficulties. The question asked whether plants could live and get food if there were no animals on earth. Because Parker did not view plants as making their own food, it was hard for him to accept the idea of plant independence that the text had stated as possible.

Thus, the text organization and questions did not challenge any of Parker's incorrect preconceptions and did not help him switch over to the conceptual change strategy. In fact, the text organization had the opposite effect of convincing Parker that he knew all this already, suggesting strategy 5 as appropriate. The questions asked in the text did not challenge Parker's incorrect notions. He ended the reading convinced that he understood photosynthesis thoroughly and that he hadn't learned much new - he'd known it all along. On the posttest, however, he consistently denied that plants make their own food and he wrote instead that plants' own food comes from multiple, external sources. He also did not change his definition of food as "anything a plant needs to survive."

Kevin's reading of Modern Science. The Modern Science text organizes the explanation of photosynthesis around a structure/function theme. Each plant part and its contribution to photosynthesis is described first. This culminates in a discussion of how all the plant parts interact to produce food during photosynthesis. Compared to the Concepts in Science text, many more details and specialized vocabulary words are given and there is much less attempt to highlight the main concepts through repetition. Like the Concepts in Science text, however, the Modern Science text does not pose questions or present explanations that challenge students to see the conflicts between their ideas about plants' food and the scientific notion of photosynthesis.

We have already seen (see p. 2) that Kevin was able to "comprehend" the concept of photosynthesis from the text explanation but was unable to change his real-world misconceptions to be consistent with this concept. Kevin read the text using the same strategy that Parker had used. He thought he already knew it all:

> "This is mostly the same (as what I had before) except for a little more detail...This is sort of like a review for me with more detail."

However, what was it that Kevin knew? Prior to reading the text he strongly held a misconception that plants have multiple sources of food which they take in from their environment:

> Food (for plants) can be sun, rain, light, bugs, oxygen, soil, and even other dead plants. Also warmth or coldness. All plants need at least 3 or 4 of these foods. Plus minerals.

It was from this perspective that Kevin began looking for "details" from the text.

It is not surprising that Kevin used this strategy of looking for details to fill into his prior knowledge. The text is loaded with details and specialized vocabulary words that grab the reader's attention. For instance, Kevin learned about the cross-section of the leaf and its cell structure, he learned about xylem and phloem, he learned about chloroplasts and chlorophyll. He fit all these details into his incorrect conception that plants take in food from external sources. For example, he explained how root hairs go far into the soil to get water and minerals, which are food for the plant. Xylem then takes food from the soil and passes it on to the leaves. In fact, the text clearly states that minerals and water in the soil are not food for the plants, but Kevin ignored this crucial sentence even after he was asked to reread it during an interview. Thus, Kevin had to distort and ignore the text to make it fit with his misconceptions. Except for that one sentence, however, the content organization of the text content did not challenge Kevin's inaccurate assumptions. In fact, the text emphasis on details reinforced Kevin's approach to reading this text. Because main ideas were not highlighted or repeated, Kevin interpreted the text as being mainly about adding details about different plant parts to his prior knowledge.

Thus, although the structure/function argument is appealing and sensible to the expert biologist, this elaborate organization was not sensible from Kevin's naive perspective. The emphasis on detail and vocabulary in both the narrative text and in text-posed questions served only to distract Kevin from the central issues. Like Parker, he ended instruction confident that he understood photosynthesis while still believing that plants take in food from the soil.

Evalina's reading of the experimental text. On her pretest Evalina identified water as one of plants' foods, alongwith sunlight, air, fertilizer, and soil. Like Kevin and Parker, she had a strong belief that plants take in multiple kinds of food from their environment. She had no idea that plants made their own food. Implicitly, like Kevin and Parker, she was defining food as anything plants need to live.

The experimental text begins by asking students for their definitions of food and their opinion about whether water, juice and sugar are food. The text then contrasts expected student answers with the scientific definition of food, that food is only those substances that provide living things with energy. Thus, student misconceptions about a definition of food and about water being a food are elicited. In addition, the contrast between students' common ideas that water is food and the scientific notion that water does not provide energy is made. The text does not, however, explain how plants get their food in this first section.

The issue about whether water is food or not created significant conceptual conflict for Evalina after she read this first section of the text. By asking for her own ideas and then presenting conflicting information, the text helped Evalina see the link (and the conflict) between text ideas and her real-world notions about plants. In her recall, she included the text's central idea, that substances must provide energy to be considered food. She also noted that using the scientific definition of food, water is not food. In answering other interview questions, however, Evalina was clearly struggling with the conflict between the text knowledge and her misconceptions:

> I: So where does the plant get its food then?
> E: Where does the plant get its food? I don't know. From the water. I think from the water.
> I: Do you think food for plants is the same as food for animals?
> E: Well, some animals they drink water...and plants they drink water too.
> I: Okay. So that's food for plants and food for animals? It's the same?
> E: Water isn't food. I learned that much (laughs). If water isn't food then what is the, what kind of food is it for the plant? But I know that my mother, she gives water to her plants...And animals have water too. I'm sure they do. I don't know.

Thus, right from the beginning, the text structure encouraged Evalina to use a conceptual change approach to processing the text. She was linking text ideas to her prior knowledge and beginning to change her own ideas to make them consistent with the text view.

Evalina was in a state of conflict about the issue of water being food when she began reading the second section of the text. In this section, students are first asked to explain some experimental evidence: Why are grass plants able to begin growing even when kept in the dark? In writing her answer to this question, Evalina fell back on her idea that they could grow because they had water. The text then asked why plants would eventually die in the dark but live in the light, and Evalina naively wrote: "Because in the dark the plant couldn't breathe. And in the sunshine it did."

The text then contrasts such expected naive answers with scientific explanations of the phenomena. It points out that both the plants in light and plants in dark in the described experiment had soil, fertilizer, and water, and yet still the ones in the dark died. Making reference to the scientific definition of food again, the text then explicitly explains that water, fertilizer, and soil are not food for plants. It asks students questions that force them to cognitively engage the conflict between these notions and their own conceptions:

> Text Question:
> "Plant food" or fertilizer you buy at the store contains minerals that help plants grow healthier, but it does not supply plants with any energy. Think back about our definition of food (look on p. 2). Is "plant food" really food by the scientists' definition? Explain.

Finally, the text introduces the concept of photosynthesis, emphasizing that it is a process of changing nonfood raw materials into energy-containing food and that it is plants' only source of food.

After reading this section, Evalina recognized that her written explanations about grass plants growing using water and then dying because they couldn't breathe were inaccurate:

> I: Why do plants begin to grow in the dark? (Evalina had written "Because they had water.") What were you thinking when you answered that?
> E: Because I always see people use water for their plants. That's why I always say water--I think that helps them grow, according to my mother.
> I: So why do plants in the dark eventually die?

E: Because they need light so they can grow and help make their food. When they're in the dark, they don't have enough sunlight to help them make their food...I think my answer was wrong.
I: You said they couldn't breathe.
E: Yeah.
I: What do you think now?
E: I think they didn't have enough food in the dark, I know they didn't have enough food because they need the light to help them make the food...

When asked the interview question about how the real-world plant sitting on the table gets its food, Evalina immediately used new knowledge from the text to answer. This in striking contrast to the way Kevin and Parker continually relied mainly on their prior knowledge to answer this question:

E: The way it gets its food is from sun, air, and water. But they told me water is not food for the plant and neither was soil. The sun helps the plant make its food. It helpt to make in in the leaves.
I: Remember what you told me the other day about how theplant gets its food? Have your ideas changed at all?
E: Ya! (laughs). Well, at first I thought it was just water because we water ours and my mother put it out in the sunlight and stuff.

Evalina's awareness of the change in her thinking was typical of students using the conceptual change strategy, and the experimental text asked questions that made students aware of these changes in their thinking.

The third day's reading reviewed what is and is not food for plants. Students were then given numerous opportunities to apply these concepts in different situations. That Evalina had undergone significant conceptual change is evident in the way she answered another application question during the interview:

I: What would happen if a box covered a plant so that only one leaf could get light?
E: I think that the ones that's under the box, it would start to die because it needs some light down on it to help it make food. And the one that's probably out in the light, it would probably help feed the plant that's under the box, because if the food is going down the stem like that, it probably would extend to some of the other leaves. But if it didn't, then those under the box, they probably wouldn't live that long, and the one's that out, it would.

She accurat_ly thought through this situation using the concept of photosynthesis. This answer stands in dramatic contrast with the answers given by Parker and Kevin to the same question:

Parker:
S: The plant would die.
I: And, can you tell me why?
S: Because one leaf alone can't support the entire needs of the plant.
I: Okay.
S: The plant needs more sunlight than that.

Kevin:
S: I imagine it would still keep groing. But.
I: Okay. Why do you think so?
S: I think it could still only survive off of one leave, but I doubt it. I don't think so.

Even when probed, they did not come up with explanations that draw from text knowledge. Instead, they developed their predictions and explanations based on their prior knowledge about plants.

Thus, the experimental text structured content and asked questions in ways very different from the two commercial texts. It asked questions to make students aware of their misconceptions, it highlighted contrasts between students' misconceptions and scientific conceptions, and it explained why each of students' common misconceptions about food for plants were inaccurate. These features helped Evalina see the relationship between the text and her real-world ideas, thus engaging her cognitively in a way that the other texts did not do for Parker and Kevin. This set Evalina up to find the explanation of photosynthesis both plausible and intelligible. Numerous application questions enabled her to see how the concept was broadly useful. In short, the structure of the text helped Evalina use a conceptual change approach to reading the text and to fulfill each of the four criteria for conceptual change learning in the Posner model.

Summary of Case Studies. The differences in the ways the three textbooks were used by these three readers cannot be attributed to differences in reading ability. Both Parker and Kevin were reading well above grade level according to standardized test results (post high school and grade 12, respectively), while Evalina was reading at a 5.6 grade level. In spite of being good readers with high interest in science, Parker and Kevin used an ineffective reading strategy that was not challenged by the content organization or questions in the texts they read. Evalina, on the other hand, used an effective conceptual change strategy that was encouraged by the structure of the experimental text. The results were striking differences in learning outcomes:

Table 3 goes here

Comparison of Learning Outcomes

Differences among students reading the three texts are also supported by the posttest analysis of student learning. These analyses clearly indicate that student learning is mediated by students' selection of text-processing strategies.

Analysis of posttest results focused on student mastery of four different scientific conceptions. Table 4 shows that six of the seven students who relied on Strategy 6, including one student reading a commercial text, mastered all four scientific conceptions. The remaining student using that conceptual change strategy mastered three scientific conceptios. None of the eleven students using the other strategies, even the one student reading the experimental text, mastered more than two scientific conceptions.

The choice of strategy, in other words, was a better predictor of student learning than the type of text read or the students' reading achievement level. The experimental text, however, clearly influenced students to choose the most effective strategy.

Table 4 goes about here

Conclusions

The study shows that students, both "good" and "poor" readers, have difficulty learning from text because they use ineffective text processing strategies. Five ineffective strategies were defined. None of these strategies enabled students to see the conflicts between text presentations of scientific conceptions and their own naive theories, or misconceptions, about the concepts. Because these strategies did not permit students to appropriately integrate their "real-world" knowledge with the disciplinary knowledge presented in the text, conceptual change learning from text was impossible.

Only students using a conceptual change strategy for processing text were successful in giving up or modifying their incorrect prior knowledge in favor of the text explanations of how plants get their food. These students were aware that text explanations were in conflict with their own experiential understanding of how plants get their food, and they used this text knowledge to change their misconceptions.

The study also demonstrated that the experimental text, which addressed and challenged student misconceptions in addition to presenting explanations of the goal concepts, was much more successful than two commercially available texts in inducing students to use the effective conceptual change strategy. As a result, students reading the experimental text did dramatically better than students reading the other texts in terms of developing meaningful understanding of the text content.

Implications

By helping us understand <u>why</u> students have difficulty learning from text, this study has important implications for research and textbook development, for teaching, and for student learning. The finding that students' misconceptions play a critical role in their interpretation (and misinterpretation) of texts opens new doors in thinking about how to improve student learning from text.

First, textbooks can be written in ways that will encourage the use of a conceptual change reading strategy and result in meaningful learning from text. Traditionally, textbooks have been written only to present scientific explanations of phenomena. This study suggests, however, that knowledge about common student misconceptions can be used to write texts that challenge students' misconceptions and help them see how these misconceptions are in conflict with scientific explanations of phenomena. A new model of textbook development is needed in which careful research on students' misconceptions serve as the foundation for textbook development. Research would also be important during pilot testing in this text development model. Such research would focus on analysis of students' conceptual change learning. Thus, students would be asked more than to just parrot back text information (What is photosynthesis?) They would also be asked questions to reveal persisting misconceptions and to diagnose failures to integrate text knowledge with real-world knowledge (How does this plant get its food?)

Teachers can help students undergo conceptual change learning from text by carefully structuring reading assignments to help students become aware of the conflicts between scientific explanations in the text and their personal theories. Questions must focus on eliciting student misconceptions, challenging those misconceptions, relating text content to real world situations, and highlighting the contrast between text and student explanations. Teachers must be aware of the limited information about student learning they are getting from asking questions that students can answer successfully using one of the ineffective text processing strategies.

The most important implication from this study is for students. The study suggests that students at all reading levels are capable of using a reading strategy that will help them make sense of text content. Thus, conceptual change learning from text is a realistic goal for middle school science students.

FIGURE 1

DESIGN OF THE STUDY

TEXT		DAY 1	DAY 2	DAY 3	DAY 4
<u>Modern Science</u> (6 students)	Pretest	Read Part 1, Interview	Read Part 2, Interview	Read Part 3, Interview	Posttest
<u>Concepts in Science</u> (6 students)	Pretest	Read Part 1, Interview	Read Part 2, Interview	Read Part 3, Interview	Posttest
Experimental Text (7 students)	Pretest	Read Part 1, Interview	Read Part 2, Interview	Read Part 3, Interview	Posttest

TABLE 1

TEXT PROCESSING STRATEGIES

		Source of knowledge for answering text-based questions	Source of knowledge for answering real-world questions	School Knowledge	Reading Goal
1.	Overreliance on prior real-world knowledge	Prior knowledge	Prior knowledge	(Prior knowledge can help you answer questions)	To finish a school task
2.	Overreliance on isolated words in text	"Big" words in the text	Prior knowledge	(Big words in text are important to use)	To finish a school task
3.	Overreliance on facts in text - additive notion of learning	Facts in the text	Prior knowledge	(Learning is memorizing lists of facts)	To memorize facts about plants
4.	Separating disciplinary knowledge and real-world knowledge as two distinct, equally sensible worlds of knowledge	Disciplinary view presented in the text	Prior knowledge	(To make sense of text, you can't try to relate it to real-world knowledge)	To make sense of text view of plants
5.	Overreliance on prior knowledge to make "sense" of disciplinary views in the text	PRIOR KNOWLEDGE Disciplinary view presented in the text	PRIOR KNOWLEDGE Disciplinary view presented in the text	-------	To make sure I'm right; to add a few details to what I already know
6.	Using text knowledge to change real-world ideas	DISCIPLINARY VIEW PRESENTED IN THE TEXT Prior knowledge	DISCIPLINARY VIEW PRESENTED IN THE TEXT Prior knowledge	-------	To make sense of text view of plants and to use text view of plant; to change view of plants

TABLE 2

STRATEGIES USED BY INDIVIDUAL STUDENTS

TEXT		READING LEVEL	DOMINANT STRATEGY		
			DAY 1	DAY 2	DAY 3
Modern Science	Linda	4.5	1	1	1
	Tracey	5.6	1	2	1
	Danny	7.1	3	2	3
	Sally	8.4	3	5	5
	Kevin	12.6	5	5	5
	Susan	12.6	5	6	6
Concepts in Science	Jill	4.0	3	2	2
	Maria	4.0	1	1	1
	Myra	6.0	3	3	5
	Phil	6.0	5	5	5
	Deborah	10.0	5	5	5
	Parker	PHS	5	5	5
Experimental	Daryl	3.4	5	6	6
	Evalina	5.6	6	6	6
	Allison	7.6	1	5	6
	Doug	8.1	4	6	6
	Vera	8.6	4	6	6
	James	11.3	4	6	6
	Sheila	PHS	5	6	6

Table 3

Comparison of Three Students' Conceptual Changes

				PRECONCEPTIONS		POSTCONCEPTIONS	
Student	Text	Reading Level	Strategy	Source of food	Defines food	Source of food	Defines food
Parker	Concepts in Science	Post high school	Overreliance on prior knowledge, #5	Multiple, external	What plants need	Multiple, external	What plants need
Kevin	Modern Science	12	Overreliance on prior knowledge, #5	Multiple, external	What plants need	Multiple, external and internal (plants make food and take in food)	What plants need
Evalina	Experimental	5.6	Conceptual change, #6	Multiple, external	What plants need	photosynthesis photosynthesis	Provides energy

Table 4

Learning Outcomes

Text	Student	Dominant Strategy	Reading Level	LEARNING OF GOAL CONCEPTS: Plants make food, do not take it in	Need light to make food	Get food only by making it	Get food from seeds at first
Experimental	Daryl	6	3.4	*	*	*	-
	Evalina	6	5.6	*	*	*	*
	Allison	mixed	7.6	-	*	-	*
	Doug	6	8.1	*	*	*	*
	Vera	6	8.6	*	*	*	*
	James	6	11.3	*	*	*	*
	Sheila	6	PHS	*	*	*	*
Concepts in Science	Jill	2	4.0	+	+	+	NA
	Maria	1	4.0	-	-	-	NA
	Myra	3	6.0	-	-	-	NA
	Phil	5	6.0	-	*	-	NA
	Deborah	5	10.0	-	*	-	NA
	Parker	5	PHS	-	-	-	NA
Modern Science	Linda	1	4.5	-	-	-	-
	Tracey	1	5.6	-	-	-	-
	Danny	3	7.1	-	*	-	-
	Sally	5	8.4	-	*	-	-
	Kevin	5	12.6	-	*	-	*
	Susan	6	12.6	*	*	*	*

KEY:
- * = understood the concept
- – = did not understand the concept
- NA = not addressed in this text
- + = did not take posttest

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