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CONCEPTUAL-CHANGE LEARNING
AND STUDENT PROCESSING OF SCIENCE TEXTS

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Abstract

This study compares student cognitive processing of and learning from a text that was written to change common student misconceptions about photosynthesis with student processing of two traditional science texts. Nineteen middle school students, each reading a sustained segment from one text over the course of three days, were interviewed after each day's reading. The interviews were designed to trace students' thinking about photosynthesis and to elicit information about students' processing of text. Analysis of interview transcripts, as well as pre- and posttest data, shows that the students reading the experimental text developed a more meaningful and consistent understanding of how plants get their food. Interview data also revealed differences in cognitive processing of the three texts. Students were classified as using six different text-processing strategies as they read and studied the text. The characteristics of the texts were important in determining the students' interactions with the texts and their choices of reading strategies. Only students using the most sophisticated text-processing strategy, labeled a conceptual-change strategy, successfully achieved conceptual change. This strategy was used by six of the seven students reading the experimental text, but by only one of the twelve students reading the other two traditional texts.
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Overview of the Study

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 text 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 19 students as they read one text chapter over a 3-day period. This approach provided detailed information about the cognitive processes 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.

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1This paper was presented at the annual meeting of the American Educational Research Association, Chicago, April, 1985.

2Kathleen J. Roth is an instructor with the teacher education department and a senior researcher with the Middle School Science Teaching Project.
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 & Wylan, 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, & Anderson, 1980; LeBoutet-Barrell, 1976). For example, in a study of student learning after activity-based instruction about photosynthesis, only 11% of 220 fifth graders ended an 8-week unit of experiments and discussions by 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, & 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
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 if it 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 him 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 find this concept useful in understanding 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 (schemata) facilitates and makes possible learning from text (Anderson, Reynolds, Scallert, & Goetz, 1977; Anderson, Spiro, & Anderson, 1978; Bransford & McCarrell, 1974; Frederikson, 1975; Meyer, 1984; Pearson, Hansen, & Gordon, 1979). 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 & Hayes-Roth, 1979). In this vein, Lipson (1983), Maria and MacGinitie (1982), Spiro (1979), and Spiro and Tirre (1980) have shown that prior knowledge can interfere with comprehension of text. It seems reasonable that this is what happened to Kevin. The research on reading, however, has not explored learning from texts in a
The overall objective of this study was to explore students' cognitive processing of three different textbooks, all covering the concept of photosynthesis, 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 as follows:

1. To identify the cognitive reading strategies used by 19 middle school students who read 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 3 days. In this way, students were able to read one text over a period of time similar to what would 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
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 and prior knowledge to answer the questions and to determine what strategies they used to answer them. Interviews were audio-recorded and later transcribed.

**Pre- and Posttests.** Pretests were administered 2 weeks prior to the study to assess prior knowledge, and identical posttests were administered 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 choices or predictions, then to explain or justify their responses. The research design is summarized in Table 1.

<table>
<thead>
<tr>
<th>Text</th>
<th>Day 1</th>
<th>Day 2</th>
<th>Day 3</th>
<th>Day 4</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Modern Science</em></td>
<td>Pretest</td>
<td>Read Part 1, Interview</td>
<td>Read Part 2, Interview</td>
<td>Read Part 3, Interview</td>
</tr>
<tr>
<td>(6 students)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Concepts in Science</em></td>
<td>Pretest</td>
<td>Read Part 1, Interview</td>
<td>Read Part 2, Interview</td>
<td>Read Part 3, Interview</td>
</tr>
<tr>
<td>(6 students)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Experimental Text</td>
<td>Pretest</td>
<td>Read Part 1, Interview</td>
<td>Read Part 2, Interview</td>
<td>Read Part 3, Interview</td>
</tr>
<tr>
<td>(7 students)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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. The 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 nine, five, and six 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, readability 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: 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.
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 5-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. We analyzed test data 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, but some evidence was given more weight.

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 definition 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
what the text said, for example, they frequently attributed the text with
having said things that were not in the text but which 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. Perfor-
mance 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 to complete a school task.** Like another group of poor readers studied by Spiro (1979), students using this strategy 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 simply isolated words that had no relationship to each other or to any prior real-world knowledge. In their recollections, 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
equal emphasis on trivial details and on main concepts, and failed to 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.

When the interviewer asked Myra whether the girl doing the experiment had made a conclusion about the role of the sun, Myra simply said, "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 in the text. This was particularly striking with these students because they had included these facts in their recall. Use of this additive notion of learning, however, prevented students from linking text information to real plants. It also prevented students from making sense of the text presentations on 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 for each to make sense. For this group of students the text explanation was
they already knew. This attitude was expressed by some as, "Basically, I had 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. 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 with their prior knowledge. Thus, these students did make some attempts to integrate real-world and disciplinary knowledge, but, 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 conflict was resolved by abandoning or changing their misconceptions in favor of the more powerful, sensible disciplinary explanation.
Table 3

Strategies Used By Individual Students

<table>
<thead>
<tr>
<th>Text</th>
<th>Reading Level</th>
<th>Day 1</th>
<th>Day 2</th>
<th>Day 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modern Science</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Linda</td>
<td>4.5</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Tracey</td>
<td>5.6</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Danny</td>
<td>7.1</td>
<td>3</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Sally</td>
<td>8.4</td>
<td>3</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Kevin</td>
<td>12.6</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Susan</td>
<td>12.6</td>
<td>5</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Concepts in Science</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jill</td>
<td>4.0</td>
<td>3</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Maria</td>
<td>4.0</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Myra</td>
<td>6.0</td>
<td>3</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Phil</td>
<td>6.0</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Deborah</td>
<td>10.0</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Parker</td>
<td>PHS&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Experimental</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Daryl</td>
<td>3.4</td>
<td>5</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Evalina</td>
<td>5.6</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Allison</td>
<td>7.6</td>
<td>1</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Doug</td>
<td>8.1</td>
<td>4</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Vera</td>
<td>8.6</td>
<td>4</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>James</td>
<td>11.3</td>
<td>4</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Sheila</td>
<td>PHS</td>
<td>5</td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>

<sup>a</sup>Post high school.
whenever 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 their prior knowledge, the *Concepts in Science* text begins with a discussion of oxygen production during photosynthesis. This is then used as an introduction to the idea that plants also produce food during photosynthesis.

How did Parker interpret this section of the text? First, 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 stress. Most of what I have studied had done, oxygen was stressed. Plants do 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 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, two-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 use the conceptual-change strategy. In fact, the text organization had the opposite effect of convincing Parker that he knew all the information already, suggesting that prior knowledge will help him make sense of the text material. 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
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, along with 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 make their own food. Implicitly, like Kevin and Parker, she defined food as anything plants need to live.
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 process the text. She linked text ideas to her prior knowledge and began 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 those in dark in the described experiment had soil, fertilizer, and water and that the ones in the dark still 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. The text asks students questions that force them to cognitively resolve the conflict between these notions and their own conceptions:

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 energy-containing food.
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:

Interviewer: What would happen if a box covered a plant so that only one leaf could get light?

Evalina: 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 cut 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 that one's that out, it would.

She accurately 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: The plant would die.

Interviewer: And, can you tell me why?

Parker: Because one leaf alone can't support the entire needs of the plant.

Interviewer: Okay.

Parker: The plant needs more sunlight than that.

Kevin: I imagine it would still keep growing. But.

Interviewer: Okay. Why do you think so?

Kevin: I think it could still only survive off of one leaf, but I doubt it. I don't think so.
used an effective conceptual-change strategy that was encouraged by the structure of the experimental text. The results were striking differences in learning outcomes.

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 5 shows that 6 of the 7 students who relied on Strategy 6, including 1 student reading a commercial text, mastered all four scientific conceptions. The remaining student using the conceptual-change strategy mastered three scientific conceptions. None of the 11 students using the other strategies, even the 1 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.

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 integrate
<table>
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<tr>
<th>Student</th>
<th>Text</th>
<th>Reading Level</th>
<th>Strategy</th>
<th>Preconceptions</th>
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<tr>
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<td>What plants need</td>
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<td>Multiple, External</td>
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<tr>
<td>Kevin</td>
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<td>12</td>
<td>Overreliance on prior knowledge, #5</td>
<td>Multiple, external</td>
<td>What plants need</td>
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<td>Multiple, external and internal</td>
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<td></td>
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<td></td>
<td>(plants make food and take in food)</td>
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<tr>
<td>Evalina</td>
<td>Experimental</td>
<td>5.6</td>
<td>Conceptual-change, #6</td>
<td>Multiple, external</td>
<td>What plants need</td>
</tr>
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<td></td>
<td></td>
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<td>Photosynthesis</td>
</tr>
</tbody>
</table>
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 to do more than 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 receive 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.


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CONCEPTUAL-CHANGE LEARNING AND STUDENT PROCESSING OF SCIENCE TEXTS

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