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ABSTRACT

This study examines the relationship between student misconceptions and learning by focusing on six fifth-grade students as they attempt to make sense of classroom instruction on light and seeing. Pretests, posttests, and classroom observation narratives served as student data. Pretests indicate that students held the misconception that sight is possible because light illuminates things, not understanding the role of reflected light in vision. Posttests indicate that five of the six students still did not understand how light enables seeing by the end of the unit. Although good teachers (two were observed) used a popular text, instruction was not successful in that conceptual change did not occur; most students did not forsake their misconception in favor of the scientific conception. Furthermore, students' belief in the misconception prevented them from fully understanding other topics covered in the unit, such as the functioning of various eye parts. Conceptual change did not occur because the students' misconception was not addressed in either the text or classroom instruction. Instead, students were taught and learned facts about light and facts about seeing. Many of them had difficulty making sense of these facts and seeing how they are connected to each other, as their answers on the posttest show. (Author/JN)

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STUDENTS' MISCONCEPTIONS INTERFERE WITH LEARNING: CASE STUDIES OF FIFTH-GRADE STUDENTS

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and Edward L. Smith

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Abstract

Students' misconceptions about scientific topics affect the ways that students understand and respond to classroom science instruction. This study examines the relationship between student misconceptions and learning by focusing on six fifth-grade students as they attempt to make sense of classroom instruction on light and seeing. Pretests, posttests, and classroom observation narratives served as student data. The students' pretests indicate that the students held the misconception that we see because light illuminates things; they did not understand the role of reflected light in vision. The posttests indicate that five of the six students still did not understand how light enables seeing by the end of the unit. Although good teachers (two were observed) used a popular text (Laidlaw's Exploring Science), the instruction was not successful in that conceptual change did not occur; most of the students did not forsake their misconception in favor of the scientific conception. Furthermore, the students' belief in the misconception prevented them from fully understanding other topics covered in the unit, such as the functioning of various eye parts. Conceptual change did not occur because student misconceptions were not addressed in either the text or classroom instruction. Instead, students were taught and learned facts about light and facts about seeing. Many of them had difficulty making sense of these facts and seeing how they are connected to each other, as their answers on the posttest show. The authors suggest that teachers be made aware of likely student misconceptions so they can work to change them.

STUDENTS' MISCONCEPTIONS INTERFERE WITH LEARNING: CASE STUDIES OF FIFTH-GRADE STUDENTS[1]

Janet F. Eaton, Charles W. Anderson, and Edward L. Smith[2]

"What's black and white and red all over?"

Think back to the first time you heard that riddle. The answer, "a newspaper," seemed obvious once someone explained it to you, but you probably could not think of it yourself. That was because you, like most people, probably heard the riddle in a way that made it impossible for you to think of the answer. Most people think to themselves something like, "Hmmm. Black and white and red. That's three colors. What do I know that has those three colors all over it?" Then they are stumped. And when they are told the answer is a newspaper, they are confused until someone spells it out for them.

"What's black and white and read all over?"

The assumption that the riddle is asking for something with three colors makes it hard to think of the answer.

Unconscious assumptions, even assumptions that are logical and reasonable, can make it impossible for people to understand scientific concepts as well as riddles. Everyone makes assumptions about the way the world works, assumptions like, "When the sky is cloudy and dark, it will probably rain," or "Bits of wood float in water." Often those assumptions are used to explain how things work, like, "I can see myself in a mirror because light bounces off

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[2]Janet F. Eaton is the IRT editor. She served as a research assistant with the Elementary Science Project. Charles W. (Andy) Anderson and Edward L. Smith co-coordinate that project. Charles W. Anderson is an MSU assistant professor of teacher education. Edward L. Smith is an MSU associate professor of curriculum.

me to the mirror and off the mirror to my eyes." Such explanations, or conceptions, are based on experience and common sense, but sometimes experience and common sense can lead to inaccurate or incomplete conceptions. Just as a false assumption in a riddle can prevent a person from thinking of the right answer, inaccurate or incomplete conceptions can prevent a student from learning.

Since the early work of Piaget (1926), researchers have been aware that children sometimes have conceptions about the world quite different from scientific conceptions. It is only in the last decade, however, that they have undertaken sustained investigations of how children understand school subjects. In reading, for example, the work of researchers such as Smith (1975) and Anderson (Anderson, Reynolds, Schallert, & Goetz, 1977) has demonstrated that students use their knowledge of the world to comprehend written text, and that students' comprehension failures are often due to misconceptions or inadequacies in their background knowledge. Davis (1981) and Erlwanger (1975) have shown that, when lacking in mathematical knowledge and understanding, students often develop ways of solving mathematics problems that sometimes produce correct answers, but are fundamentally wrong because they are based on a misconception of how mathematics works.

In science, too, researchers have found that misconceptions affect the way children understand a variety of scientific ideas. For example, Nussbaum and Novak (1976) found that although most second-grade children know that the earth is round, some of them think of the earth as a planet off somewhere in the sky, not the planet they live on. Other children believe that the earth is round and flat like a pancake, or that we are on the "top" of a spherical earth, and that people on the "bottom" are likely to fall off.

The purpose of the study reported here is to examine in detail the relationship between some fifth-graders' misconceptions about light, the science textbook the students used, their classroom instruction, and what they learned--to construct what Erickson (Note 1) calls "stories of cognitive learning" of six students as they attempt to make sense of their textbook and classroom instruction on light and seeing.

We hope this paper will stimulate teachers not only of science, but of all school subjects to develop strategies for identifying and eradicating misconceptions that interfere with their students' learning. We also hope it will prod curriculum developers and researchers to give teachers more help in their efforts to do so.

Method

The Elementary Science Project, of which this study is a part, focused on the science teaching of 14 fifth-grade teachers, five teaching about light and nine teaching about photosynthesis, noting especially the way they used commercial program materials in their teaching. The teachers were selected primarily because they were within driving distance and because, unlike many elementary school teachers (Stake & Easley, Note 2), they taught science regularly. In this paper we look closely at the students of two of those teachers, whom we shall refer to as Ms. Baxter and Ms. Lane. We focus on these two teachers here simply for illustrative purposes. Their difficulties were common to all the teachers we observed.

Both Ms. Baxter and Ms. Lane used the Exploring Science text (Blecha, Gega, & Green, 1979), published by Laidlaw Brothers. We focus on this text here because it was the text the teachers normally used; they all liked its easy-to-read style and colorful illustrations. Specifically, we look here at the way they taught and the way their students learned the content of Unit 4, "Light." We present anecdotal accounts of these two teachers and six of their students. The students, three from each class were also chosen simply for illustrative purposes; their classmates responded similarly to the lessons.

Teaching

The two teachers were observed and audio-recorded as they taught lessons in the unit on light. Observers recorded detailed information describing the classroom as a whole, including noise level, teacher and student activities and comments, and teacher and student location on a standardized form developed for this purpose (Hollon, Anderson, & Smith, Note 3). The observers dictated detailed narratives, based on their notes, of each lesson; these were then typed. Thirteen lessons were observed, six for Ms. Lane and seven for Ms. Baxter.

Tests

Before the light and seeing unit was taught, the students took a pretest. After the unit, they took the same test again. The test included short-answer and multiple-choice questions (see Figs. 1 and 3 for examples). The test data from the six sample students served as the basic source of information about the students' conceptions of light and seeing before and after the unit was taught.

Results

Pretests

At the beginning of the unit, pretest data showed that all six students held a common misconception about light and seeing: They believed that we see because light shines on things and brightens them; the students did not realize that we see because the light shining on objects is reflected off them to our eyes.

Our evidence for this assertion comes from the student's answers to questions on the pretest. Figure 1 shows each student's answers to the pretest's first two questions as examples.

None of the students was aware of the role that bouncing or reflected light plays in seeing. In this respect they were typical of their classmates. Only 3 of the 102 students who took the pretest mentioned reflection or bouncing light in their answers to Question 1. Only 5 students drew arrows from the tree to the boy in their answers to Question 2.

We believe that understanding the role of reflected light in seeing is instructionally important. It is certainly essential to comprehension of large portions of the unit on light in the Exploring Science text. The chapter on color vision, for instance, describes how pigments in objects reflect some colors of light and absorb others. The descriptions of how our eyes work also depend on the understanding that we see the light that is reflected off objects to our eyes, rather than the actual objects.

Posttests

After the students had studied the unit on light, they took a posttest. The answers (see Figure 2) of five of the six students reveal little change in their ideas about how we see. Only Denise[3] seemed to understand the essence of the scientific conception (see Figure 2), although she was confused about the distinction between light and images. These results are typical of the overall posttest results. About 30% of the 113 students who took the posttest mentioned bouncing or reflected light in their answers to Question 1; about 24% drew arrows from the tree to the boy in Question 2. Overall, on the basis

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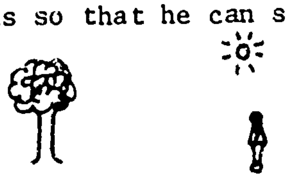
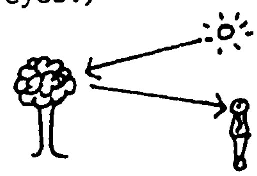
[3]All students' names in this paper are pseudonyms.

Questions and Textbook Answers	
Pretest Question 1: How does light help us see?	Answer Based on Textbook "Light shines on things and bounces off them to my eyes." (Blecha et al. 1979. p. 145)
Pretest Question 2: This boy sees the tree. Draw arrows to show how the light travels so that he can see the tree. 	Answer Based on Textbook Arrows go from sun to tree then to boy's eyes.) 

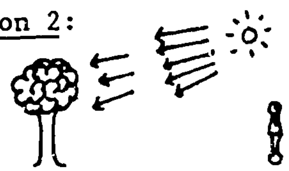
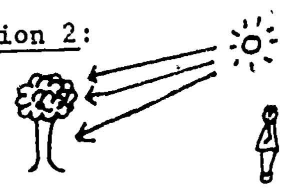
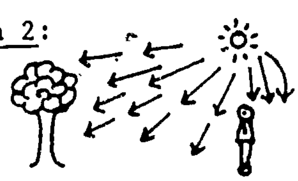
Student Answers	
George Question 1: "It brightens the path to the object we are looking at." Question 2: No answer.	Sarah Question 1: "It could help us see where we are going." Question 2: No answer.
Mark Question 1: "Well, if there wasn't light people would bump into things and people could see things." Question 2: 	Nancy Question 1: "It lights up our way so we won't bump into things." Question 2: 
Denise Question 1: "In the dark you can't see anything so it makes things so you can see it." Question 2: 	Laurie Question 1: "So you can see it." Question 2: 

Figure 1. Student answers to Questions 1 and 2 on pretest.

Questions and Textbook Answers

Posttest Question 1:

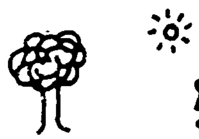
How does light help us see?

Answer Based on Textbook

"Light shines on things and bounces off them to my eyes." (Blecha et al., 1979, p. 145)

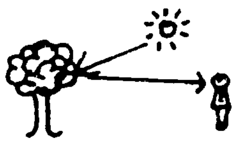
Posttest Question 2:

This boy sees the tree.
Draw arrows to show how the light travels so that he can see the tree.



Answer Based on Textbook

Arrows go from sun to tree then to boy's eyes.

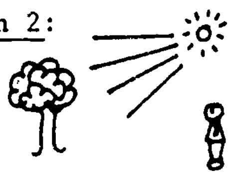


Student Answers

George

Question 1: "It lights them up."

Question 2:



Sarah

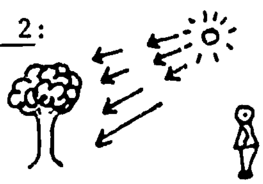
Question 1: No answer.

Question 2: No answer.

Mark

Question 1: "Without light we would run into things."

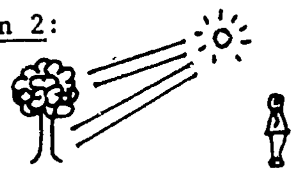
Question 2:



Nancy

Question 1: "It lights up the object so you can see it."

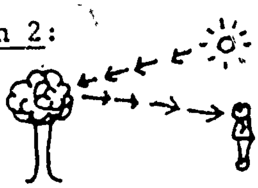
Question 2:



Denise

Question 1: "Light bounces the object's image to your eye."

Question 2:



Laurie

Question 1: "So we can see it clearly."

Question 2:

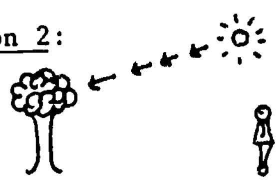


Figure 2. Student answers to Questions 1 and 2 on posttest.

of the answers to these and other questions, we concluded that about 22% of the students understood the role of reflected light in seeing (Anderson & Smith, Note 4).

After several weeks of studying light and seeing, why were most students still clinging to misconceptions about how we see? How could they read aloud in class, but fail to comprehend, clear statements in the textbook like the following?

> When light travels to something opaque, all the light does not stop. Some of this light bounces off. When light travels to something translucent or transparent, all the light does not pass through. Some of this light bounces off. When light bounces off things and travels to your eyes, you are able to see. (Blecha et al., 1979, p. 154)

In spite of this explanation, several of the students did not pick up on the fact that "all the light does not stop" when it hits an opaque object.

Another posttest question asked the students to tell what would happen to light after it hit a white piece of wood, an opaque object. That question and the six students' answers are given in Figure 3. George, Mark, and Nancy knew that light won't go through a piece of wood, but did not know that the wood would reflect light.

It seems, then, that most of the students had difficulty understanding and believing that opaque objects reflect light to our eyes. The misconception that opaque objects do no more to light than stop it, and that we see such objects simply because light shines on them, rendered meaningless much of the material the students were taught from Unit 4.

Why Didn't the Students Learn?

The existence of the misconception at the beginning of the unit is understandable, but why did it persist through four weeks of instruction in Ms. Lane's class and six weeks in Ms. Baxter's?

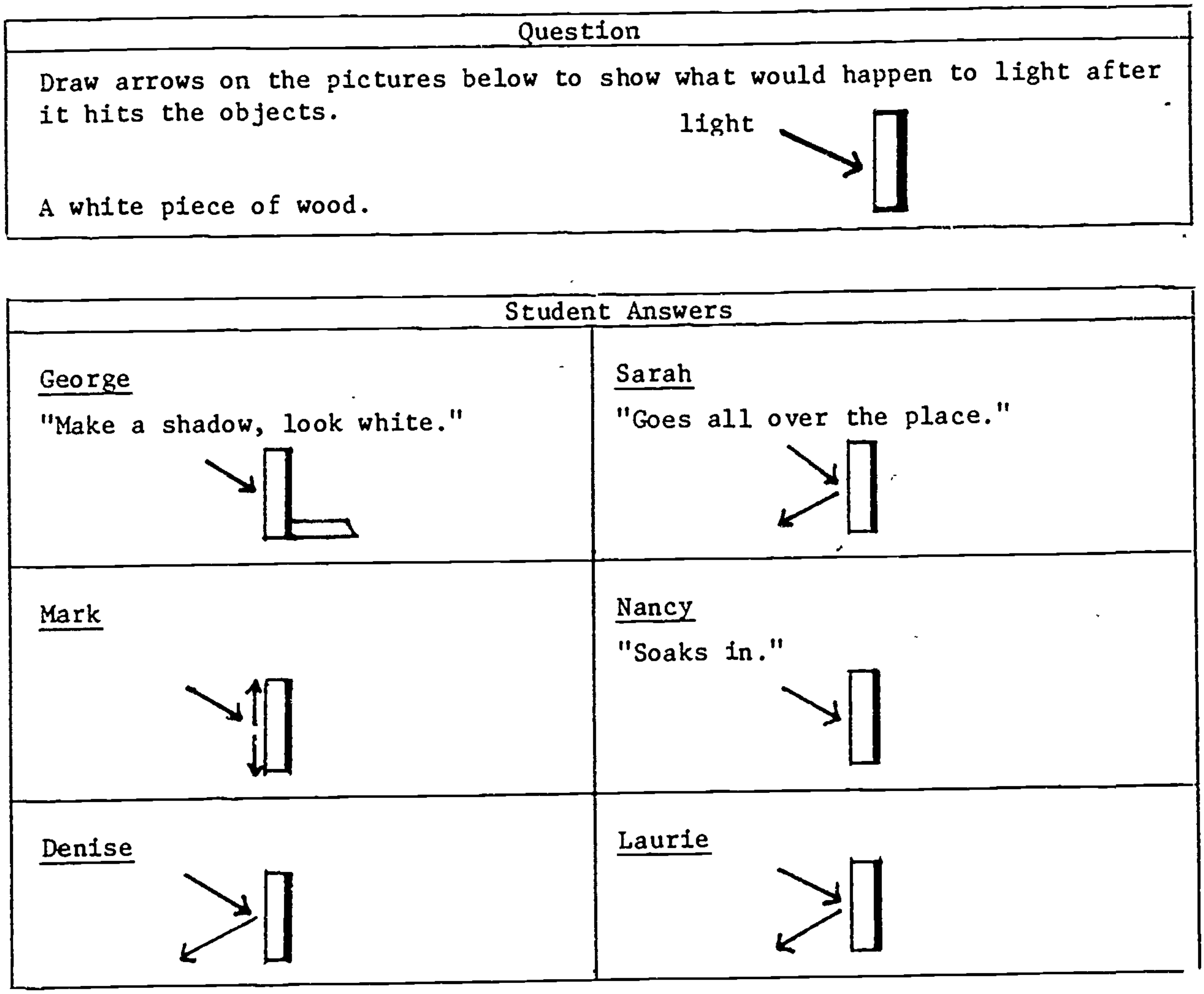


Figure 3. Student answers to Question 10 on posttest.

It was not because fifth graders are incapable of understanding these concepts or because the teachers were incapable of teaching them. When Ms. Lane and Ms. Baxter taught the light unit to their fifth graders the following year, using materials we developed to help teachers identify and address students' misconceptions (Anderson & Smith, Note 5), they were much more successful. About 79% of their students understood the scientific conception at the end of the unit.

It was not because the students were inattentive. Observers recorded the number of students on task and off task every 10 minutes during lessons. Compared with teachers in another study using similar observation procedures (Anderson, 1979), Ms. Lane's student on-task behavior rates were above average, and Ms. Baxter's were average. Serious management or discipline problems were not observed in either class.

It was not because the students used a text rather than a hands-on program. We have observed students studying photosynthesis using the activity-based Rand McNally SCIIS (Knott, Lawson, Karplus, Thier, & Marshall, 1978) experience similar learning difficulties (Smith & Anderson, Note 6).

We believe the students had difficulty learning about light because neither their text nor their teacher adequately dealt with their misconceptions.

The Text

In *Exploring Science*, the unit on light is divided into an introduction and three chapters: "Pathways of Light," "Color," and "Seeing is More than Looking."

Introduction to the unit. Preceding the three chapters is an introduction page with a cartoon on it about mirrors. On that page are the questions, "What are some things that help you see? How do these things help?" The teacher's guide provides a sample answer to these questions:

> Light shines on things and bounces off them to my eyes. My eyes send messages about what I look at to my brain. Then I see things. (Blecha et al., 1979, p. 145)

That is the scientific conception, the answer to the riddle of how light helps us see, but the teacher's guide neither stresses its importance nor suggests what the teacher should do if students do not give the sample answer.

> Of course, your pupils' responses may vary, and in many instances there are no right or wrong answers. The purposes of listing sample answers are to alert you to the kinds of answers your pupils are likely to give and to help you in guiding the discussion of the various features. (Blecha, et al., 1979, p. T11)

The authors of the teacher's guide present the scientific conception as a likely student answer. Yet in the classrooms we observed, it was the least likely student answer; it was the conception the students needed most to learn. In fact, the students in Ms. Baxter's class, when asked to list things that help us see, gave such answers as "binoculars," "glasses," "eyes," and "seeing-eye dogs." Ms. Lane made up her own introduction to the chapter and did not discuss page 145 with her students. Thus, the six students did not hear a statement of the scientific conception as the unit began.

Like most students, they started the unit believing that we see because light shines on things and brightens them. How might the text be interpreted by students with this misconception?

<u>Chapter 1</u>. "Pathways of Light" begins with a discussion of light sources. By way of introduction, the text asks the students to think about why they are able to see the things around them. The most important reason, states the test, is that "light was shining on the things you saw" (p. 146). That statement, although true in a sense, does not challenge or contradict the

students' misconceptions. In fact, it reinforces them. Perhaps a better statement would be this: The most important reason is that light was reflected off the things you saw to your eyes.

Next, the students read that light travels fast and that it makes shadows because it travels in straight lines. States the book:

> Light cannot pass through a tree trunk. Because light travels in straight lines, it cannot travel around the tree trunk. So, light stops at the tree trunk, leaving a shadow behind it. (Blecha et al., 1979, p. 148)

The idea that some light bounces off the tree trunk is not mentioned. If a child believes the misconception, there is nothing here to contradict it. In fact, the text seems to reinforce it.

The next topic addressed is how light passes through objects. The book defines translucent and transparent, explaining that translucent objects scatter light and transparent objects let it pass through, adding that sometimes transparent things, like lenses, bend light. Nowhere in this section do the authors say anything about reflected light. Again, the misconception is not contradicted. Again, it is subtly reinforced.

The idea of bouncing light is next addressed. Here, for the first time, the authors present the idea that light bounces:

> When light travels to something opaque, all the light does not stop. Some of this light bounces off. When light travels to something translucent or transparent, all the light does not pass through. Some of this light bounces off. When light bounces off things and travels to your eyes, you are able to see. (Blecha et al., 1979, p. 154)

Unlike many paragraphs in the text, this paragraph does not end with a question. The teachers we observed usually stopped to discuss the text only when there was a question. There are no cues to the teacher or students that this is an important idea. Therefore, the statement, though read in both classes, was not emphasized by either teacher, and apparently was not understood by most students. Furthermore, the picture of light bouncing in the text shows light bouncing off a mirror. Our pretest results indicate that most children, including all six sample students, believe that light does bounce off mirrors but not off ordinary opaque objects.

The authors continue their discussion of bouncing light with a discussion of "bouncing pictures." Smooth, shiny things, the students are told, reflect light in such a way that one can see one's image in them. "Rough, dull objects" scatter light so that no image is formed. Here, for the second time, the scientific conception is explicitly stated, but without emphasis. Did the six students understand that "rough, dull objects" include cars and pencils and people and most of what we see? On the basis of their answers on the posttest, it appears that they did not.

The main problem with the first chapter is one of omission. The chapter's initial explanation lacks vital information about how light enables seeing. When that vital information, the scientific conception, is presented, later in the chapter, it is usually in a paragraph making a point about some other aspect of light. Its manner of presentation may lead a young reader to consider it an added, unimportant detail.

Chapter 2. "Color" begins by asking the students to think about why color is important to them. It then tells them that white light is made up of seven colors and that there are different kinds of white light (e.g., fluorescent, incandescent).

In presenting these ideas, the text contradicts two other misconceptions held by the students. Five of the six students indicated by their answers on the pretest that they believed the first of these other two misconceptions, that white light does not contain all colors of light; they thought of it as "pure" or "colorless." The sixth student wrote that she did not know if white light contained all colors of light or not. Mark and Nancy still held the misconception that white light is colorless when they took the posttest. They seemed to think of color as something added to light. Nancy wrote that blue light was a mixture of colors: white plus blue. Furthermore, we believe on the basis of other evidence (Anderson & Smith, Note 5) that most students believe the second of these other two misconceptions, that color is a property of objects rather than of light (e.g., most people say, "The book is red," rather than, "The book is reflecting red light.")

The next section, on the color of things in sunlight, presents the scientific conception only indirectly:

> As stated before, you see the color of things because of the way light bounces off them. Suppose you look at a car in the sunlight. If the car looked white, all the colors of the sunlight would be bouncing to your eyes. (Blecha et al., 1979, p. 163)

Notice that the word "color" is used in two subtly different ways in the above paragraph. When the text refers to the "color of things," the authors are using color in the common, everyday sense, as a property of objects. However, the phrase "colors of the sunlight" refers to the scientific conception of color as a property of light. Thus, as in earlier quoted passages, the text subtly reinforces students' misconceptions while presenting scientific information.

(The section goes on to explain that pigments give objects their "color" and that different pigments soak up and reflect different "colors of light.")

The above passage is intelligible only to students who understand that (a) we see reflected light, (b) color is a property of light, not objects, and (c) white light contains all colors of light. Of the six target students, only Denise had even a chance of understanding the chapter on color.

(Subsequent sections of the chapter discuss the color of the sky and note that things look different under different colors of light.)

Chapter 3. "Seeing Is More Than Looking" begins with the idea that seeing is important. The text asks, "What are some ways being able to see has helped you keep safe or understand people?" After a single sentence reminding the students that they see things because light bounces off them to their eyes, the book tells what the various parts of the eye do when light enters the eye. How might the function of eye parts be interpreted by students who do not understand that we see reflected light?

Mark's answer to another question on the posttest shows one attempt to make sense of information he had read but not quite understood. When asked to write a story about how light helps us see, he took the perspective of a light ray and wrote,

> One day the sun shoot me at a book whech made some shadows. The book was removed and I went in a eye. The corned was transparent when I went therough the pupil then progected on to the retinia and through the nerve in the brain.

Because Mark didn't believe light was reflected off the book, the only way he could get the light into the eye was to move the book out of the way. Because he didn't understand that opaque objects reflect light, he couldn't figure out where the light that enters the eye comes from.

(The final sections of the chapter discuss images, moving pictures, and optical illusions.)

Thus, the text, though it mentions the important idea that we see light reflected from objects, neither emphasizes the idea nor explicitly contradicts the related misconceptions held by most students. Apparently, the text did not induce the process of conceptual change in most of the students.

The six sample students also had access to another source of information, the events of actual classroom instruction. The approach taken to instruction by each teacher is examined in the next section.

Instruction

Ms. Baxter. Ms. Baxter, who taught Denise, Nancy, and Laurie, followed the book closely. Her primary method of science instruction was to have her students read the text out loud, one paragraph at a time, and to have them answer the questions in the text. After a student read a section from the book, the teacher elaborated on it to make sure the students understood it. She also had the class do most of the suggested hands-on activities and demonstrations.

From the introduction on page 145, she asked one of the questions mentioned earlier: "What are some things that help you see?" As noted earlier, "binoculars," "glasses," "eyes," and "seeing-eye dogs" were the students' responses. No one mentioned light bouncing off objects, which is what the book gives as its sample answer. The teacher accepted their answers and moved on.

The students gave reasonable answers to the questions they were asked, and it was both reasonable and in line with the recommendations in the teacher's guide for the teacher to accept those answers. Yet because this opportunity to discuss the scientific conception was not taken, Denise, Nancy, and Laurie probably continued to hold their misconceptions.

In addition to using the book, Ms. Baxter asked her students to look up six words in the dictionary: light, lens, image, opaque, transparent, and translucent. Light was defined as "a form of energy that stimulates the eyes and makes it possible to see things," opaque as "not allowing light to pass through," and translucent as "allowing light to pass through, but blocking a view of objects on the other side." These are the definitions that Denise, Nancy, and Laurie wrote down. They are good, working definitions, but they stop short of a scientific explanation of light and seeing; they do not connect seeing with light bouncing off objects.

In the next science lesson, the class read the section in the book on bouncing light and transparent, translucent, and opaque objects. "Would the light bounce off the object if it was transparent?" asked Ms. Baxter? The students said that it would go through. In response to the same question regarding translucent objects, the students said that the light would go through and spread. (The teacher did not ask about opaque objects.) The teacher and students usually talked about transparent and translucent objects in terms of "seeing through" them. They did not discuss the connection between "light passing through" and "seeing through." The relationship between those phenomena may seem obvious to people trained in science, but the pretest data indicate that the students did not understand it.

During the lessons we observed from Chapter 1, reflected light was mentioned only in relation to mirrors. We recorded six different occasions when the teacher mentioned light reflecting off mirrors, but no occasions on which she mentioned light reflecting off other objects.

When the class reached Chapter 2 (Color), the reflection and absorption of "colors" and "colored light" were frequently discussed. It seems that for Denise, Nancy, and Laurie, however, "color" and "light" did not mean the same thing. They probably had great difficulty following a discussion in which the two terms were used almost interchangeably.

When Ms. Baxter's class talked about light and seeing, they referred to seeing as detecting reflected light only nine times during the seven lessons we observed, and eight of those times involved seeing images in mirrors or seeing colors. Only once, during the review lesson on the last day of the unit, did the teacher mention that we see because light bounces off things and travels to our eyes. She said, "Light bounces off things and travels to our eyes. That way you see an image."

Ms. Lane. Ms. Lane, who taught George, Mark, and Sarah, supplemented the text with information from the encyclopedia and with demonstrations and hands-on activities. She began the unit by defining light as a kind of energy. Then she asked her students to list light sources and decide whether they were natural or artificial. She also said that light travels "so we can see," and that light travels very fast--at the speed of 186,000 miles per second. She stressed that light is necessary for seeing five times during this lesson, but did not explain the role of light in enabling us to see.

When the class discussed shadows, they concentrated on the idea that light travels in straight lines and cannot pass through opaque objects. They did not note that opaque objects also reflect some light.

The issue of seeing color necessitated talk about seeing reflected light. The authors of Exploring Science write that pigments in objects absorb some colors and bounce back others. By her own admission, Ms. Lane did not feel comfortable teaching about pigments. This was evidenced by her class's discussion of color vision. She and her students tended to use the word "color" to describe both properties of light and objects (i.e., there is colored light and there are colored objects), and they used the word "pigment" as a synonym for "color."

After studying color, the students in Ms. Lane's class learned about the human eye. Ms. Lane very much enjoyed teaching the unit on the human body, and, in some ways, considered the section on the human eye an extension of that unit. Through drill and repetition, just about everyone in the class learned the names and locations of the major eye parts. Once the students had that down, they discussed the function of each part.

Ms. Lane explained the functions of the parts of the eye in terms of light entering the eye, but seldom explicitly stated where that light was coming from. Only once during the six lessons that we observed did we hear her make such a statement. She said,

> Vision, or seeing, is really, then, our eye receiving the image from the reflection of the light around us on the object, whether you are looking at the blackboard or the person in front of you. The light is reflected from them so that you can see them.

We recorded 11 occasions when reflected light was mentioned in her classroom, yet her students did not seem to understand light and seeing at the end of the unit. A closer look at those 11 occasions sheds some light on this.

How we see color was the subject of discussion on five of the occasions on which reflected light was mentioned. Twice, students remarked that they couldn't see the color of a shiny object because there was too much reflected light on it--too much glare. For instance, a student remarked, "When you look at it (an apple) real hard, you can see the light shining off it." Another student explained bioluminescence (incorrectly) as living things reflecting light. Not only, then, was the concept of seeing objects by seeing the light they reflect mentioned only once, reflected light was mentioned most frequently as "shine" or "glare"--something not directly connected to seeing objects.

Not surprisingly, George, Mark, and Sarah ended the unit with their misconceptions unaltered by instruction.

<u>Summary</u>. What both teachers did was reasonable. They did not stress the scientific conception of how light enables seeing, but the <u>Exploring Science</u> textbook gave them no indication that they should. The teachers followed the book carefully and tried to teach the unit well, but most of their students did not come to understand the role of light in seeing.

Discussion

Is it important that students learn that we see reflected light? We think it is. Students need some sort of conceptual framework to link all those definitions and facts about light together. If the scientific conception is not explicitly stated and explained, they are likely to stick with a misconception that makes sense to them. Every new term or theory will be integrated into that faulty conceptual framework. To such students, science will, ultimately, make little sense because there will come a time when their faulty conception does not work. Their misconception cannot adequately explain how we see colors, how our eyes function, how microscopes and telescopes magnify, or how cameras take pictures. Only if a student understands the scientific conception do explanations of these things make sense.

The unit can be thought of as a riddle, much like the riddle mentioned earlier. "How does light enable us to see things?" is as much a trick question to many children as "What's black and white and red (read) all over?" Just as the word "read" has a double meaning in the riddle, the words "light" and "see" have subtly different meanings for people who believe the scientific conception than for those who believe the misconception.

The riddle of light and seeing was never solved for most of the children we observed. They never heard and understood an explicit explanation of what light and seeing really mean.

Learning with a Preconception

As a reading of our posttest data reveals, most of the students we observed began the light unit believing that light brightens objects so we can see them. What was instruction like for them? Everything they were taught was either consistent with their misconception or so disconnected from it as to seem irrelevant.

For example, one of the first things the students learned was that light travels very fast. As Figure 4 illustrates, this can be easily interpreted as consistent with the misconception they held.

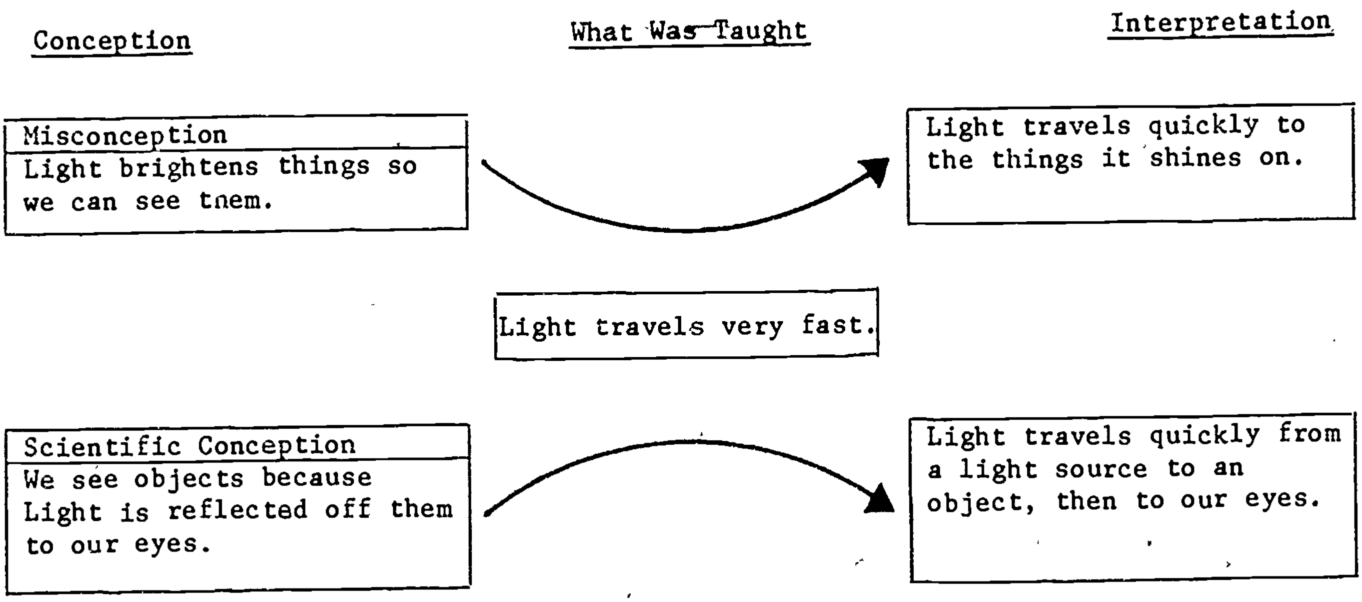


Figure 4. Two interpretations of the effects of light traveling fast.

Thus, the children could, and many did, learn that light travels fast without learning how light enables seeing.

The students next learned that light travels in straight lines. Again, this is consistent with both conceptions (see Figure 5). Thus, without understanding how light enables seeing, the students could easily learn that light travels in straight lines.

The chapter on color was disconnected from the first chapter. The students were taught that we see color because colors of light are absorbed by pigments or reflected to our eyes, but they did not connect this with seeing

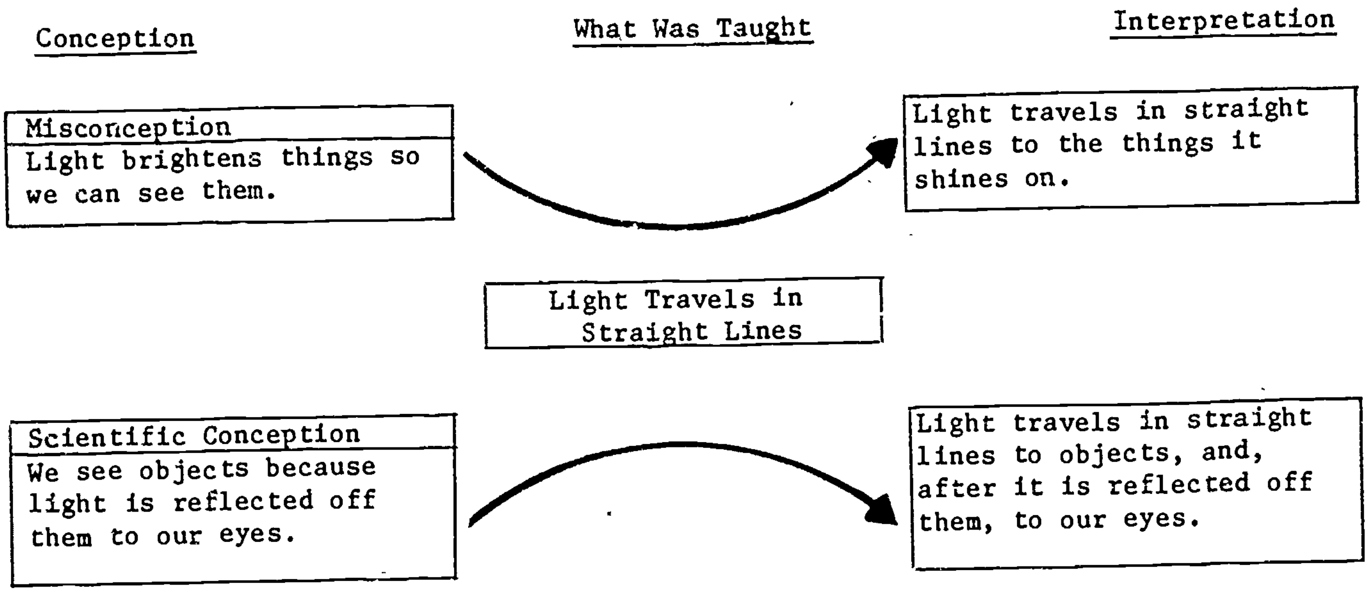


Figure 5: Two interpretations of the effects of light traveling in straight lines.

objects. They had no conceptual framework within which to understand what pigments do, so they never understood how pigments were related to color and colored light.

When the students studied the eye, neither the teachers nor the text explicitly stated and explained the connection between light entering the eye and the seeing of objects. Thus, the students discussed light entering through the pupil, being bent by the lens, being focused on the retina, and so on, but they never understood where that light was coming from, or how it helps us to see objects.

Why Did Denise Learn?

How, in spite of all this, did Denise manage to learn the scientific conception? Denise wanted to learn, and she demonstrated this to the observer during the lesson in which the students were to copy definitions of vocabulary words from the dictionary. The observer asked Denise for an example of something translucent. Denise didn't know any examples, but at the end of the lesson she came up to the observer and told him she had asked the teacher for an example and had found out that tissue paper is translucent. Denise didn't like unanswered questions.

Although we sometimes asked such questions of other students, Denise was the only one to find an answer to a question she had been unable to answer and to tell the observer about it. She was serious about learning and knew how to seek answers to questions that troubled her. Denise and other students like her were exceptionally sensitive to the conflicts between what they read and heard and their own ideas, and they were not satisfied til they resolved those conflicts.

Such students formed a minority of those we observed. (Just 22% of the 113 students who took our posttest demonstrated an understanding of the scientific conception.) It is not enough to succeed only with those students who are as motivated and able as Denise.

<u>What Can Be Done?</u>

It takes more than a simple statement of the scientific conception to alter the beliefs of students like those described in this paper. Their strong commitment to their misconceptions and the subtle reinforcement of those misconceptions during instruction prevented most of them from even realizing that an alternative way of understanding light and seeing existed.

The scientific conception must be carefully explained and contrasted with common misconceptions. In a sense, it must be proven to the students' satisfaction. They must understand how the scientific conception is different from and more adequate than their own or they will probably not understand it.

One way to help students might be to revise already popular science texts, to make explanations of scientific phenomena so crystal-clear and reasonable that a misconception does not stand a chance. That, however, is no easy task.

While clear textbook explanations, especially explanations that contradict common student misconceptions, may go a long way toward improving student science comprehension, they are probably not enough. A textbook may be the mainstay of many curricula, but it is not the only part. Teachers can help to make texts comprehensible for their students, and teacher's guides can and should equip teachers to do that.

It would, therefore, be fruitful to revise teacher's guides. We would like to see teachers' guides alert teachers to common student misconceptions. We would also like to see teacher's guides provide teachers with a conceptual framework for each topic within which to teach the facts, theories, and ideas of science. This would help teachers decide what to stress and what to leave out if time is pressing. Teachers need more complete information from textbook authors if they are to make intelligent instructional decisions about how to use the text.

The Exploring Science text and teacher's guide clearly lacked these qualities, as do most other texts. When we surveyed the treatment of light in five other elementary, middle, and high school textbooks (Leonard, Note 7), we found that all of them shared, to a greater or lesser extent, the problems we identified in Exploring Science.

During the year after the observations reported in this article were made, we attacked the problem of inducing conceptual change by developing a series of transparencies for teachers to use with the text and an accompanying teacher's manual (Smith & Anderson, Note 5). The 13 transparencies contrast misconceptions with scientific conceptions, showing why and how the scientific conceptions work. The teacher's manual alerts teachers to their students' probable misconceptions and suggest strategies for identifying and dealing with them.

With use of the new materials, student understanding of the role of reflected light in seeing improved dramatically: 78% of the students understood the concept as opposed to 22% of the students observed during the project's first year, before the materials were developed. Ms. Lane and Ms. Baxter were among the teachers who used these new materials with their fifth graders. By the unit's end, 88% of the students in Ms. Lane's class and 71% of the students in Ms. Baxter's class understood the role of reflected light in seeing. Such materials can be of great help to other teachers, too.

Equally important, though, is research on student conceptions of other important scientific topics. Analyzing student conceptions is a difficult and time-consuming process; it is not something that teachers should be expected to do in their spare time. Researchers can make a valuable contribution to science education by identifying common student misconceptions and telling teachers about them.

Without this knowledge, many science lessons may fall as flat as an unexplained riddle. All a student may be able to say after such lessons is, "I don't get it."

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