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ABSTRACT

This study is part of a larger study of teachers' use of curriculum materials in planning and teaching fifth-grade science. The study focused on one of nine teachers observed teaching "Communities," an activity-based unit from the SCIIS science program (a revision of the original Science Curriculum Improvement Study). "Communities" is designed to introduce students to groups of organisms interacting in biological communities: producers, consumers, and decomposers. Observations of instruction and measurement of learning were completed during teaching of units on producers (plant growth and photosynthesis). Although the teacher became aware that students held certain misconceptions about plant growth, she was unsuccessful in helping them replace their misconceptions with the scientific conceptions she wanted them to learn. The analysis revealed several factors contributing to this disappointing result. Teachers and curriculum developers held different views about learning and the nature of science. In addition, several problems surfaced about the content and organization of the teacher's guide. Implications for and suggestions related to elementary science instruction, development of teaching guides, and teacher education are considered and a list of important teacher education outcomes that should be addressed, such as knowledge of common misconceptions and specific strategies for changing them, is included. (JN)

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PLANTS AS PRODUCERS: A CASE STUDY OF ELEMENTARY SCIENCE TEACHING

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Abstract

This case study is part of a larger study of teachers' use of curriculum materials in planning and teaching fifth-grade science. This case study focuses on one of nine teachers observed teaching an activity-based unit on plant growth and photosynthesis. Although the teacher became aware that her students held certain misconceptions about plant growth, she was unsuccessful in helping them replace their misconceptions with the scientific conceptions she wanted them to learn. The analysis revealed several factors that contributed to this disappointing result: The teachers and the curriculum developers held different views about learning and the nature of science, and several problems surfaced about the content and organization of the teacher's guide.

PLANTS AS PRODUCERS: A CASE STUDY OF ELEMENTARY SCIENCE TEACHING[1]

Edward L. Smith and
Charles W. Anderson[2]

Ms. Howe's[3] fifth-grade class had been conducting a science investigation in which they had planted grass seed in the light and in the dark. After two weeks of careful measuring and observing of the grass and several rigorous discussions of the results, Ms. Howe had the students answer a brain teaser in which they were to predict whether or not seeds starting to grow in a dark mine would survive and then explain their predictions.

When the lesson was finished and the students had left for gym, the observer asked Ms. Howe if there had been anything surprising about the lesson.

Ms. Howe replied, "Uh, huh! It was horrible! Most of them [the students] think that it [the germinated seed] is going to survive."

Looking through the students' science manuals left on the desks, Ms. Howe noted that Sue had written that plants can make their own food if they have water and light, but that while Mike had started his explanation similarly, he had ended up writing that plants get their food from the soil.

Pete's answer particularly dismayed her. Although he had described a dying houseplant to her earlier, he had not realized that the grass the students had been growing in the dark also matched his description.

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[1]Paper presented at the annual meeting of the National Association for Research in Science Teaching, Fontana, Wisconsin, April 1982.

[2]Edward L. Smith and Charles (Andy) W. Anderson, coordinate the IRT's Elementary Science Project. Smith is an associate professor of administration and curriculum and Anderson is an assistant professor of teacher education; both are in MSU's College of Education.

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

"Was it [the dying houseplant] like what is happening [with the grass grown in the dark]?" Ms. Howe had asked him. He had responded, "No, it wasn't that yellow."

"That was so weird!" exclaimed Ms. Howe. "It just blew my mind!" Pete had not realized the grass was dying.

She read Pete's explanation of why the germinated seeds would survive in the dark mine: "We made tests to see if they [grass plants] could grow in the dark and they grew but that they were a different color than they were supposed to be."

Pete was one of Ms. Howe's better students. Yet in her view, he had misunderstood the significance of the experiment. "That was the biggest disappointment," said Ms. Howe.

Ms. Howe had guided her students through careful observations and measurements. She was confident that they were with her and ready for the brain teaser. How could they have failed to understand evidence that was crystal clear to her?

Context

This incident occurred during a case study of activity-based teaching. Ms. Howe was one of 14 teachers observed as part of a study of planning and teaching of fifth-grade science. Nine of these teachers used an activity-based program and five a textbook series.

Our research focused on four aspects of the teaching-learning situation: the curriculum materials (especially the text and teacher's guide), the teachers' planning, actual classroom interaction, and student conceptions of the topics covered. Analysis of curriculum materials included identifying the major concepts and principles the students were expected to develop. Tests were then developed, including short answer and prediction-explanation questions designed to reflect alternative student conceptions. Data collection included observations and tape recordings of teacher planning and classroom teaching, teacher interviews, and pre- and posttesting of students.

Ms. Howe was one of seven[4] teachers we observed using *Communities* (Knott, Lawson, Karpus, Thier, & Montgomery, 1978), the fifth-grade life science unit of the Rand McNally SCIIS program. Although the present article reports our analysis of one teacher, it reflects important features common to all or most of the other teachers we observed using the SCIIS materials. Results of our analysis of teaching using the textbook are documented elsewhere (Slinger, Anderson, & Smith, Note 1; Eaton, Anderson, & Smith, Note 2; Anderson, & Smith, Note 3).

The Classroom

Ms. Howe taught in a racially mixed fifth-grade class in a well equipped, self-contained classroom. The school, a modern, single-level structure, was located in a student housing complex near a large midwestern university. Ms. Howe was in her sixth year as a classroom teacher.

The Science Program

SCIIS is an activity-based program in which students perform a series of investigations rather than reading a textbook. The major components of the program are the teacher's guide, a kit containing equipment and supplies, and student manuals with questions and spaces for recording data and answers to questions.

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[4]The other two teachers (of the nine using an activity-based program) used the SCIS II version of the *Communities* unit, which was published by American Science and Engineering in 1978. Both SCIIS and SCIS II are revisions of the original SCIS (Science Curriculum Improvement Study), and are quite similar to each other.

Communities is designed to introduce students to the groups of organisms that interact in biological communities: producers, consumers, and decomposers. Our study focused on Chapters 3 through 6, in the part covering producers. The major ideas that these chapters develop are (a) that green plants use food stored in the seed to begin to grow and (b) that after this food is used up they must have light in order to make their food and survive.

During Chapter 3 activities, students dissect bean seeds and discover parts that they label *embryo* (a small plantlike structure) and *cotyledons* (the two halves surrounding the embryo of the seed). During Chapter 4, they attempt to germinate various combinations of seed parts and find that only whole seeds or embryos attached to a cotyledon develop. These results and the observed changes in the seed parts support the idea that the cotyledons provide nourishment or "food" for the embryo, which develops into a mature plant.

During Chapter 5 activities, the students attempt to grow grass in the light and in the dark. The grass begins to grow under both conditions. However, the grass in the dark eventually dies while the grass in the light continues to grow. These results support the idea that plants use food in the seed to start to grow but need light to continue. The concept of photosynthesis is, in SCIIS terminology, to be "invented" in this chapter and used to explain the results.

During Chapter 6 activities, students remove the cotyledons from some young bean plants but not from others. Half of each group are placed in light and half in the dark. The anticipated results can be predicted and explained in terms of the ideas developed in the earlier chapters.

Ms. Howe's Teaching

Near the end of Chapter 5, Ms. Howe discovered that her students' observations of grass growing in the light and in the dark were not, as she had expected, leading them to conclude that the grass plants needed light to survive or that they used light to make their food. Table 1 presents a summary of the events leading up to the episode of her discovery, which was described at the beginning of this paper.

How could the students have failed to understand evidence that Ms. Howe saw as crystal clear? We believe that three major factors contributed to what was for Ms. Howe a surprising, if not shocking, result: (1) the differing conceptions of plant growth and nutrition held by Ms. Howe and her students, (2) Ms. Howe's psychological beliefs about how students learn, and (3) her epistemological beliefs about the relationship between evidence and scientific theories.

Ms. Howe was in most respects an excellent teacher. She had good rapport with her students and expressed interest in and affection for them. She liked them and they liked her. The friendly atmosphere of the classroom did not exist at the expense of discipline or control. A business-like atmosphere generally prevailed, and when it did not, she took prompt action to correct the situation. Equally important, she showed concern for and attention to student learning.

Ms. Howe's orientation toward learning appears more salient when compared to that of Ms. Ross, the teacher described by Smith and Sendelbach (1982) in an earlier case study. Ms. Ross was oriented toward doing the activities suggested by the teacher's guide with the hope that learning would result. While learning was not unimportant to Ms. Ross, in her planning for science she placed a relatively low priority on considering what learning was to be promoted in specific lessons. This was the last step in her planning; often she did not explicitly consider it.

Table 1

Summary of Ms. Howe's Lessons For Chapter 5

Lesson	Date	What Happened
1	January 30	The first half of the lesson was a long (28 minute) discussion of procedures for and questions related to the planting of the grass. Ms. Howe presented the question, "Do plants need light to grow?" as the purpose of the experiment, but it was not discussed. Students planted grass seeds in cups of soil and placed them on trays to be kept in the light or dark. The question was posted on each tray as suggested in the teachers guide.
2	February 6	The class discussed whether plants get food from the soil and whether plants need light to grow. Having observed the grass in the dark growing, most students agreed with the statement that plants do <u>not</u> need light to grow. Following a brief discussion of where plants get their food after their cotyledons are gone and what would happen to the plants in the dark, the students measured and observed the grass plants and switched two of the cups from light to dark and vice versa. At this point the grass in the dark was yellow and taller than that in the light, which was green.
3	February 9	The class briefly discussed why the grass in the dark was growing better, again agreeing with the idea that plants do not need light to grow. They then measured and recorded data on grass height, noting that the grass in the light was leaning toward the windows.
4	February 11	After the students measured and recorded heights of the grass, Ms. Howe had them observe and then describe one plant from the light and one from the dark. Students reported that the grass in the light was straight, stronger, and dark green with little white, while that in the dark was crooked, weaker, and light green (in student's words) with a lot of white. The class then discussed the role of light in plant growth with students suggesting that light makes the plants "healthier," is "like vitamins," and provides "warmth" or "nutrients."
5	February 12	Ms. Howe had the students carefully observe two plants, one switched from light to dark and the other from dark to light, in order to guess which was which. Over half the class correctly choose the grass that was yellow (author's color assessment) shorter, and erect as moved to the dark and the grass that was green, taller, and drooping as moved to the light. Ms. Howe summarized, stressing the difference in color. At this point Ms. Howe assigned the brain teaser, the results of which were portrayed in the vignette with which this paper began.

In contrast, Ms. Howe was oriented toward learning; she used suggested activities to promote specific learning outcomes. In describing her unit planning, Ms. Howe stated:

> Basically, I went to Part 1 and looked at the objectives--I guess maybe I'm objective oriented ... [to] see what they are trying to get across to the children, and [to] see if I agree. Do I want to get those things across or do I want to add something.

Ms. Howe's teaching clearly reflected this orientation toward learning. She often asked questions and used student observations to develop specific ideas. She usually examined the plants before school to determine what specific observations could be made and then planned ways of using those observa tions in class.

This strategic use of students' observations and discussions had characterized Ms. Howe's handling of the grass experiment in Chapter 5. She had wanted her students to develop the idea that plants cannot survive in the dar because they must have light to make their food. As can be seen in Table 1, she had never presented this idea directly. Rather, she had made sure that her students measured and observed carefully and had held a series of discussions in which she had pressed the students to be clear about their observations and to try interpreting them. She had expected those observations to lead the students to develop the idea of photosynthesis.

In using this strategy, Ms. Howe believed that she was being faithful tc the discovery or inquiry-oriented philosophy of the SCIIS program, as exempli fied in the title of the SCIIS training film, "Don't Tell Me, I'll Find Out." She assigned the brain teaser at a time when she was sure that the students had collected enough data to develop the idea of photosynthesis. In order tc understand why they were not developing that idea, it is necessary to consid(what was happening from the students' point of view.

Students' Preconceptions[5] and Experience of Instruction

Ms. Howe's students took a pretest that reflected aspects of their beliefs concerning plants, food, and light. On the pretest most students expressed the belief that plants need light. Most also stated that the plants need light to live and grow. Others stated that light is necessary for the plants to be healthy but not for them to continue to grow.

When the students observed that grass began to grow in the dark, their view that plants need light to live and grow was shaken. After observing specimens of grass from the closet in Lesson 2 (Table 1), the students nearly unanimously asserted that plants do not need light. The observation that the grass in the dark was actually taller than that in the light probably contributed to this belief.

As the students continued to observe the plants through Lessons 3 and 4, they used such words as "dark green," and "stronger," and "straight" to describe those in the light, while those in the dark they labeled "light green" or "yellow," "weaker," and growing "in all directions." This was consistent with the view that plants need light to be healthy, and more students appeared to develop this conception. In Lesson 4, several students used the word "healthier" to describe plants in the light, and one suggested that "light is like vitamins for the plant."

As the measurements and observations were continued and discussed at length, the students became very clear about the relationship between light and the observed color and condition of the plants. By Lesson 5 they were

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[5]Preconceptions are what students bring to instruction. Not all of their preconceptions were incorrect. For example, plants *do* need light to live and grow over a prolonged period of time. Sometimes correct conceptions, not anticipated by the teacher, can cause problems.

able to infer which of two cups of grass had been started in the dark and switched to the light and vice versa. This was good evidence of the accuracy of their observations because both cups of grass showed some characteristics of the grass always in the light and some characteristics of the grass always in the dark.

Ms. Howe interpreted the clarity of the students' knowledge of these results as evidence that they realized that the grass in the dark was dying. She, therefore, assigned them the brain teaser posing the issue of the survival of plants beginning to grow in a dark mine. The students' responses and her reaction are described in the vignette at the beginning of the paper.

In Ms. Howe's view, the grass in the dark was clearly dying of starvation. However, the students had little basis for assuming that the observed lack of color and strength would be fatal. The evidence was consistent with their conception that plants are simply more healthy if they have light. Thus, many of the students predicted that the plants would survive in the dark mine, some noting further that the plants would not be green or healthy. A few predicted that the plants would not survive, explaining this in general terms of the plants' need for light. Contrary to Ms. Howe's expectation, no students predicted both that the plants would die and explained this in terms of the plants' inability to make food without light.

Actually, at this point there was little reason for the students to associate the plants' condition with food. On our pretest, the students had been nearly unanimous in their assertion that plants need food. However, the most frequently expressed ideas about what that food is were "water" and "fertilizer" or "plant food." Other students included materials such as air, soil, and even light. Although not explicitly expressed, it appears that the students' responses were based on a conception of food for plants as the materials that plants take in from their surroundings rather than the materials plants use for energy and growth.

The students' ideas that water and fertilizer are food for plants had surfaced several times in discussions of the experiment in which students attempt to germinate various seed parts (Chapter 4). Given these ideas of what plants' food is, they frequently stated that plants get food from the soil. On these occasions, Ms. Howe tried to lead them to the conclusion that plants do *not* get food from the soil, a point emphasized in the teacher's guide. However, because their underlying conceptions of food as materials plants take in remained unchanged, her efforts were difficult for the students to understand. Ms. Howe repeatedly cited the growth of seeds in the germination systems (which contain no soil) as evidence that plants do not need soil or fertilizer to grow. She developed the idea that fertilizer makes plants healthier, but is not necessary for growth. While this idea was understandable to the students, from their point of view this did not necessarily imply that fertilizer is not food. (Regarding humans, for example, an argument like Ms. Howe's could be made about broccoli; broccoli is good for people, but they can get along fine without it.)

In contrast to the observed evidence that plants do not need fertilizer to grow, the students continually saw evidence that plants *do* need water. The students' idea that water is food was seldom challenged. When it was, Ms. Howe referred to the plants (or the embryos) getting food from the cotyledons instead of from water. However, the students had no particular reason to assume that plants can only get food from one source.

As the idea that plants get food from the cotyledon was developed to explain the growth of the bean embryo attached to a cotyledon, some of the students began to mention the cotyledon as a food source. This idea appears to have lived a shaky existence alongside the idea that water, and perhaps fertilizer, are also food for plants. Ms. Howe never addressed the issue of what the food from the cotyledon is. Most students continued to believe food is whatever plants take in from some source--water, soil, or cotyledons--and few students saw any connection between the light experiments and food for plants.

These student ideas about plants, food, and light help explain the differences between Ms. Howe's interpretation and theirs of the results of the grass experiment. The students had little reason to associate the poorer health of the plants in dark with lack of food since they continued to view food as materials that plants take in. Further, no connection had been made to the grass getting food from its cotyledons. Indeed, they had not considered whether or not the tiny grass seeds even had cotyledons.

Ms. Howe was dismayed to discover that the students were not putting the pieces together. However, from the students' perspective, the connection between light and food had not been made. The situation at the time that Ms. Howe assigned the brain teaser is summarized in Figure 1. Ms. Howe and her students, making the same observations from different conceptual perspectives, interpreted what they saw quite differently.

The Significance of Ms. Howe's Problem

We believe Ms. Howe's problem of getting her students to understand that plants make their own food to be significant because it typifies the problems experienced by teachers we have observed using the SCIIS program. It has its roots in Ms. Howe's assumptions about the nature of science and about how students learn. These assumptions contributed to Ms. Howe's misinterpreting the *Communities* teacher's guide in certain important ways. Her difficulties were exacerbated by the fact that the teacher's guide did not provide her with

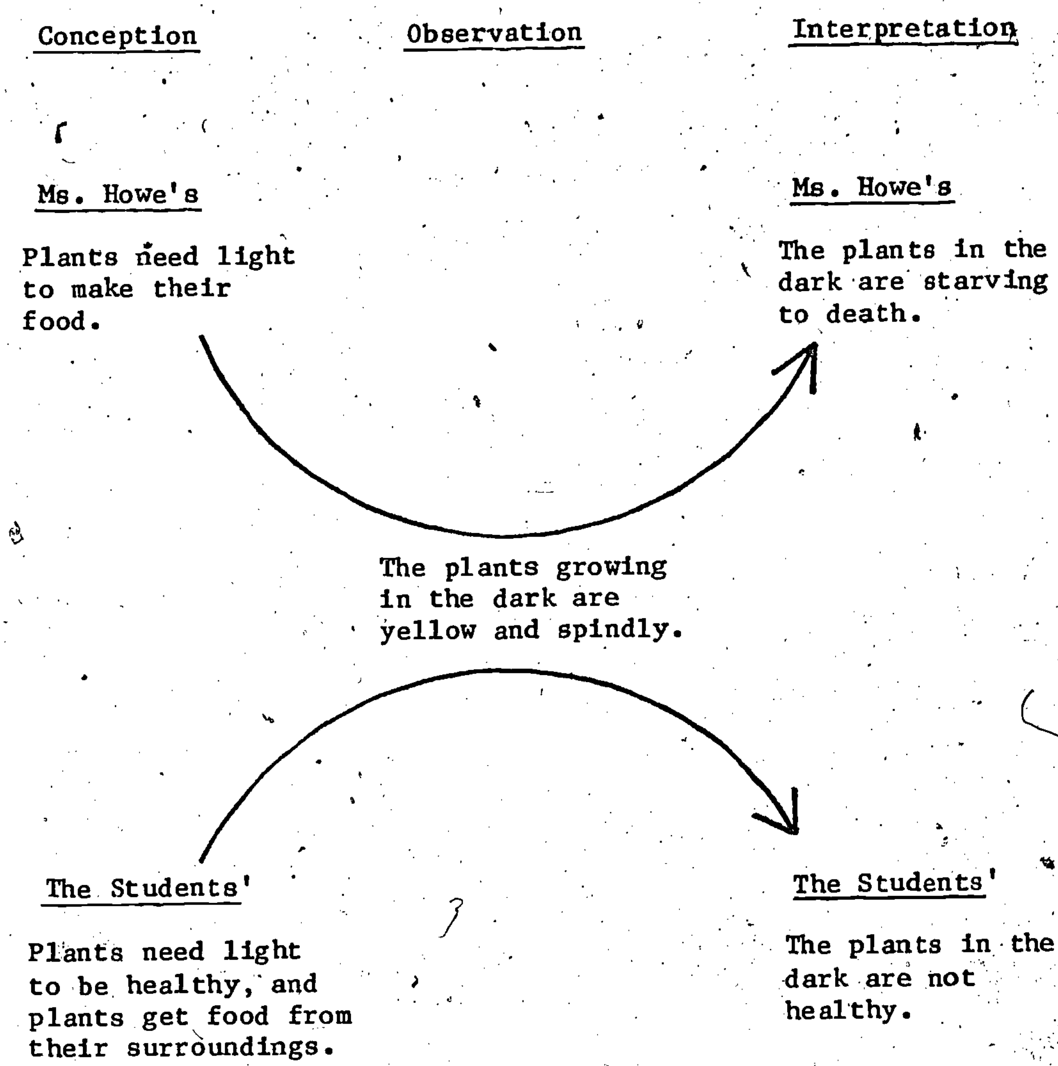

Figure 1. Contrasting interpretations of the same observation by Ms. Howe and her students.

some critical information in a useful form. Each of these aspects of the problem is discussed below.

Ms. Howe's Assumptions About Science

Ms. Howe was surprised to discover that even though her students were making detailed and accurate observations, they were not, as she said, "getting" the idea of photosynthesis. Her surprise stemmed in part from her implicit beliefs about what science is and how scientific theories are created. Ms. Howe believed that photosynthesis, a theoretical construct, could be derived in a fairly straightforward manner from empirical observations of plants grown in the light and dark.

Ms. Howe's beliefs were consistent with the philosophical position of logical positivism, which holds that scientific theories are inferred from data through inductive logic (Cawthron & Rowell, 1979). Science is, therefore, viewed as a progressive enterprise in which more and more true facts about the world are discovered over time.

Modern philosophers of science such as Kuhn (1970) and Toulmin (1972), and their predecessors going back to Kant and Hume, have questioned the logical positivist assumption that scientific theories are inferred from data by inductive logic. Instead, they have claimed that theories are inventions of the human mind that determine what data are collected and how those data are interpreted.

Ms. Howe, of course, made no claim to be a philosopher of science. Her assumptions about science, however, are important for three reasons. First, those assumptions led to her incorrect belief that her students would be able to derive the concept of photosynthesis from their observations. Second, her beliefs contributed to her misinterpretation of some crucial points in the *Communities* teacher's guide. Finally, most of those studying to become elementary school teachers (Cotham & Smith, 1981), and other teachers we have observed also share this view of science. Thus, Ms. Howe is not an isolated case.

Ms. Howe's Assumptions About How Students Learn

Discovering conceptual change. Initially, Ms. Howe viewed the evidence that was growing out of the students' investigations as leading logically to the ideas she expected the students to learn. She therefore gave little attention to the ideas that the students might already have. Her own understanding of the goal conceptions enabled her to view the evidence as clearly indicating that the grass plants growing in the dark initially got some food from their cotyledons but that they were slowly dying of starvation.

She was surprised, if not shocked, by the students' failure to share her interpretations. She became more and more aware that the students had alternative ideas that they would not readily give up. At this point, her understanding of learning began to reflect conceptual change, that is, that learning was a matter of the students changing their initial ideas and adopting new ones, rather than simply acquiring the ideas that she had hoped to teach.

While Ms. Howe's understanding of the significance and persistence of the students' misconceptions had improved, she appears not to have understood sufficiently their roots and their relationship to the goal conception well enough to enable her to put together a strategy for bridging the gap. In particular, she appears not to have recognized that most students saw no connection between the condition of the plants in the dark and a lack of food.

This may also explain why Ms. Howe did not recognize the importance of a question in the teacher's guide leading to the introduction of photosynthesis: "Plants need food for growth, just as animals do. Where does their food come from?" She reported trying to find a way to introduce the role of light to the students and indicated that she had looked at the very column of the teacher's guide on which this question is found. Lacking a clear grasp of the contrast between the students' conceptions and the goal conception, she was unable to see the relevance of the question.

Inferring versus inventing. Ms. Howe's failure to pose the question concerning the plant's food source appears to have been an important omission from the instructional strategy of the program. However, a second, even more significant deviation was her failure to present a definition and explanation of photosynthesis to the students as suggested. When Ms. Howe decided that her students were clearly aware of the observable differences between the grass plants in the light and those in the dark, she assigned them the brain teaser about the survival of plants beginning to grow in the dark mine. Her expectations were not only that the students would predict that the plants would not survive, but also that the students would explain this in terms of plants' inability to make food in the dark.

Ms. Howe's approach contrasts with that suggested in the SCIIS teacher's guide, where this brain teaser is not introduced until after the investigation to be done in the next chapter. At about the point where Ms. Howe did use the brain teaser, the SCIIS teacher's guide calls upon the teacher to present the concept of photosynthesis to the students (Knott et al., 1978, p. 24). This suggestion reflects the SCIIS "learning cycle" in which new explanatory concepts are "invented" (clearly presented by the teacher) after student "exploration" in which appropriate observations and questions are developed (Knott et al., 1978, p. xviii).

Thus, while Ms. Howe believed that students could somehow infer photosynthesis from their observations, the SCIIS view, which parallels that of philosophers such as Kuhn and Toulmin, is that such concepts are creative inventions that students are not very likely to happen upon.

Limitations of the Teacher's Guide

As implied above, the teacher's guide appears to have outlined a strategy which, if implemented, might have succeeded in bringing about a conceptual shift in the students, leading them up to the point of readiness and then introducing the concept of photosynthesis. The preceding paragraphs have suggested that Ms. Howe's beliefs about the nature of learning from the activities helps to account for her failure to implement this strategy despite its availability in the teacher's guide.

However, this can be turned around and interpreted as the teacher's guide failing to adequately communicate the nature of the learning and the suggested instructional strategy to Ms. Howe. While aspects of the students' anticipated preconceptions are identified in the guide, and while the suggested instructional strategy does appear to be workable, it is obvious from the experience of Ms. Howe and the other teachers we have observed that the guide does not communicate either the instructional strategy or its rationale to most teachers. The ingenuity of the underlying instructional strategy suggests that the developers were much more aware of the significance and nature of the students' preconceptions than is suggested by the minimal treatment that they are given in the teacher's guide itself.

Furthermore, the specific roles of the various observations and discussions in effecting change in the students' conceptions are not made explicit in the teacher's guide. For example, the only clues in Chapter 5 that the teacher is to present the definition and explanation of photosynthesis is that the information is in italics and the term "invent" is used. There is also the brief statement, "You introduce the concept of photosynthesis," in the overview to Part I of the teacher's guide, a section of the teacher's guide that Ms. Howe omitted in her review during unit planning. It is unlikely, however, that that single statement would have significantly changed her view.

On the other hand, the paragraphs on the "invention" part of the SCIIS learning cycle do make the nature of the invention act quite clear. Here again, however, it is located in a five-page explanation of "Helping Children Learn with SCIIS" to which Ms. Howe did not attend during her planning.

While it might be suggested that Ms. Howe should have spent more time planning and reviewing the various parts of the teacher's guide, it should be recognized that she had already spent a relatively large amount of time both planning and preparing for the teaching of science. The tasks of ordering, obtaining and planning for the use of materials, scheduling of events, organizing the classroom, adjusting for the exigencies of growing plants, and dealing with a classroom full of fifth-grade children are strong competitors for time to be devoted to reflective consideration of remote sections of the teacher's guide.

The difficulty of developing an understanding of the instructional strategy from the teacher's guide is reflected in our own experience. Despite general understanding of the approach and our extended analysis of the teacher's guide at the outset of our investigation, it was only as a result of our observations of students and teachers working through the activities that we have come to understand the nature and significance of the students' particular preconceptions and the ways in which the instructional strategy embedded in the teacher's guide seems to anticipate them.

Epilog

Ms. Howe conducted one more formal lesson on the grass experiment following the one lesson we described in the vignette. Before class, Ms. Howe restated to the observer that the students' responses to the brain teaser had convinced her that they did not yet understand the role of light in plant growth. During class she had the students measure and record the length of the grass. She then had them calculate the growth of four samples of grass from the light and four from the dark.

When calculations of growth did not produce clear cut patterns favoring the plants in the light, Ms. Howe had the students carefully describe the difference between samples of grass from the light and dark. She then showed them a cup of grass from the dark and asked them to predict what would happen next and then explain why.

Again, Ms. Howe did not raise the question of the plants' source of food or present the idea of photosynthesis. One student did suggest that the sun "helps to produce its own food," but when other students were unable to follow up on this suggestion, Ms. Howe ended the discussion referring to the bean plants for Chapter 6 growing in the closet, and indicating that they would talk more about the cotyledon and the sun later.

After class Ms. Howe stated that some of the students seemed to be beginning to understand the role of light, but that she believed many of the students had still not gotten the function of light in plant growth straight. These remarks reflected her continued commitment to teaching the idea of photosynthesis to her students. Her teaching strategies, however, reflect her continued misinterpretation of the strategy implicit in the teacher's guide. Her response to the sudents' failure to develop the idea of photosynthesis by themselves was to have the students make more observations and then press them for interpretation. Her increasing awareness of the problem did not lead her to improved understanding of the suggested solution.

On several occasions Ms. Howe had expressed her difficulty with finding a good way to introduce photosynthesis to the students, on one occasion adding, "Maybe they expect you to use an [audiovisual] aid." Although she later attempted to conduct the experiment for Chapter 6, Ms. Howe essentially abandoned the teacher's guide at this point. Over the next week she launched a veritable media blitz. During four science classes the class viewed and discussed two filmstrips; rotated through a series of learning centers at which they watched additional filmstrips, made drawings, and did other activities; and listened to a filmstrip/record presentation. This blitz included several presentations about photosynthesis as well as a variety of other information about plant growth.

Our posttest data indicate that Ms. Howe's effort met with mixed results. Four students (20%) seemed to develop a fairly sound understanding of the goal conceptions reflected in the SCIIS teacher's guide. Only these students seem to have abandoned the idea that plants take in food. Many apparently simply added "making food" to their list of food sources for plants. While most (80%) of the students ended up with some awareness that plants make food, only 45% realized that they do so only if they are growing in the light.

Of the teachers we observed, Ms. Howe was probably the most aware of the difficulties the students were experiencing. She was also among the most successful in getting students to learn the goal conceptions. The limited success she experienced (and the sense she was left what that the program itself does not work) suggest a need for efforts to assist teachers in improving the effectiveness of their use of the SCIIS materials.

Implications

The significance of this case study arises partly from the many good qualities of both the SCIIS program and the teacher. In contrast to SCIIS, the other science program that we investigated (Blecha, Giga, & Green, 1979), provided no information about children's preconceptions; they recommended a teaching strategy that was unworkable even if followed absolutely correctly (Eaton, Anderson, & Smith, Note 2). Our impression, based on a series of studies involving several different programs and over 50 teachers (Anderson, 1979; Smith & Sendelback, 1982; Anderson & Smith, Note 5; Anderson & Smith, in press), is that SCIIS is among the most philosophically and psychologically sophisticated programs available.

Similarly, Ms. Howe's problems emerge clearly partly because of her many good qualities as a teacher. She managed her classroom well, she prepared carefully, she understood the science content, and she was clear about what she wanted her students to learn. When teachers of Ms. Howe's quality experience such limited success in teaching science, we feel that it should be a cause for major concern about the quality of training and support that educators provide to elementary school teachers.

The problem we have described can be viewed as one of failure to provide teachers with the knowledge they require to implement the instructional strategy implicit in the unit. Two levels of knowledge are required: (1) the detailed knowledge of the specific unit and (2) knowledge of the conceptions of teaching and learning strategy employed in the units.

The *Communities* unit is designed to induce conflicts between students' misconceptions and their observations. However, to actually achieve such conflict, the teacher must be aware of the specific misconceptions, the relevant observations, and the role of the suggested questions. This awareness is also required for the timely introduction of the concept of photosynthesis. These and other elements together constitute the specific knowledge of the strategy for that section.

For specific knowledge of this strategy to be attainable and functional, however, the teacher must have or develop conceptions of teaching and learning that reflect those implicit in the strategy. This, as we have illustrated above, seldom happens. This failure to impart required pedagogical knowledge to teachers has implications for both curriculum development and teacher education.

Development of Teacher's Guides

While the instructional strategy implicit in the *Communities* unit may be adequate for achieving conceptual change in students, the teacher's guide does not reflect an adequate strategy for assisting teachers in changing their conceptions about teaching and learning. Although it is not clear how far a teacher's guide can take a teacher, there is considerable potential for improving the degree to which teacher's guides make explicit critical information and promote necessary shifts in the teachers' conceptions of teaching and learning. Further, much can be done to improve the fit between the organization of information in teacher's guides and the teachers' typical pattern of use. We suggest the following:

1. The conceptual change aspect of learning must be made much more explicit and evident.

2. Information about expected student preconceptions should be clearly presented.

3. The goal conceptions (the desired state of student's knowledge) should be clearly presented and identified as such.

4. The roles of the specific learning activities in promoting students' conceptual change should be made explicit.

5. This information and the conception underlying it needs to be woven into the fabric of the teacher's guide, not simply appended as explanatory information at the beginning of the guide or in chapter introductions.

Guiding students successfully through experiences of conceptual change is a considerable challenge. Teachers need more than a set of suggested steps to follow; they need to understand the purposes of the recommended activities.

Specific information about students' likely preconceptions, activities that will generate evidence that confronts students' misconceptions, and explanations of how that evidence may be used in bringing about desired conceptual changes provide a knowledge base that may allow many more teachers to successfully meet this challenge.

Teacher Education

The problems discussed above have implications for both the content and methods of teacher education. An important goal of teacher education should be the development of the idea of conceputal change in learning. That is, teachers should understand that rather than having no knowledge at all, learners beginning to study a topic usually have their own preconceptions, some of which are misconceptions that must be changed. Teacher educators need to realize that their students (future teachers) have conceptions of learning and teaching that are probably very different from theirs. Teacher educators must develop and apply strategies for changing any misconceptions of teaching and learning, just as classroom teachers must change their students' content-related misconceptions.

The generic level of knowledge represented by conceptions of learning and teaching is crucial, but it is not sufficient. Teachers also need specific knowledge for topics they are to teach. Teacher educators should address such knowledge for several topics. This would not only prepare teachers to teach those topics, but would develop a fuller sense of what it means to be prepared to teach a topic and promote a deeper understanding of the generic conceptions.

Among the important learning outcomes teacher education should address are the following:

1. a conceptual change view of learning,

2. knowledge of generic strategies useful in achieving conceptual change,

3. knowledge of common misconceptions for several important topics and specific strategies for changing them,

4. skill in selecting and adapting curriculum materials based on common preconceptions held by students,

5. skill in diagnosing student conceptions and recognizing them from student responses, and

6. a view of theory as invented to account for observations rather than deriving objectively and reliably from them.

Teacher education should lay a foundation and provide a substantial base of specific pedagogical knowledge. Teacher's guides, continuing education, and professional reading can add to this base. Researchers and teacher educators face a large but important task in developing and effectively communicating this essential knowledge.

Reference Notes

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