DOCUMENT RESUME

ED 237 493 SP 023 322

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TITLE Teaching for Conceptual Change: Some Ways of Going Wrong. Final Report.
SPONS AGENCY Michigan State Univ., East Lansing. Inst. for Research on Teaching.; National Inst. of Education (ED), Washington, DC.
PUB DATE Jun 83
GRANT NIE-G-81-0094
NOTE 26p.; Paper presented at the International Seminar on Misconceptions in Science and Mathematics (Ithaca, NY, June 19-22, 1983).
PUB TYPE Reports - Research/Technical (143) -- Speeches/Conference Papers (150)

EDRS PRICE MF01/PC02 Plus Postage.
DESCRIPTORS *Attitude Change; Cognitive Development; Cognitive Processes; *Concept Formation; Elementary Education; Elementary School Students; Elementary School Teachers; Grade 5; Instructional Development; *Prior Learning; Program Evaluation; Science Instruction; *Scientific Concepts; *Student Attitudes; Student Development; Teacher Effectiveness; Teaching Methods
IDENTIFIERS *Conceptual Change Theory of Knowledge; *Instructional Effectiveness; Misconceptions

ABSTRACT

Research has established that students generally possess conceptions relevant to curricular topics before they begin to study them and that these preconceptions often persist despite instruction on scientific theories which contradict them. Discrepancies between students' post instruction conceptions and the scientific theories as taught often represent important failures of instruction. The existence and persistence of students' preconceptions implies that learning involves not only the acquisition or formation of new concepts, but also modification of existing concepts or their replacement with appropriate alternatives, i.e., conceptual change. Reported are study results that analyzed changes in fifth-grade students' conceptions that did (and did not) occur as they experienced instruction designed to change their conceptions of how green plants get their food. It is noted that the instruction was based on chapters 3-6 of the Rand McNally SCIIS "Communities" unit. The strategy for the instruction sequence of the "Communities" unit is outlined in detail and a discussion of four ways (empirical ambiguity; ambiguity in discourse; attacking the wrong preconception; and loose framing of important issues) in which teaching for conceptual change can go wrong is presented. Implications for analysis and interpretation of empirical studies of conceptual change are also discussed. (JMK)

final report

TEACHING FOR CONCEPTUAL CHANGE:
SOME WAYS OF GOING WRONG

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Paper presented at the International Seminar on Misconceptions in Science and Mathematics: Cornell University, Ithaca, New York, June 19-22, 1983.

This research was supported by a grant from the National Institute for Education (Grant No. NIE-G-81-0094) and by the Institute for Research on Teaching and the Department of Administration and Curriculum at Michigan State University. This paper does not necessarily express the opinions, policy or position of the National Institute of Education.

As the present seminar and the volume of papers attest, it is now well established that students generally possess conceptions relevant to curricular topics before they begin study of them. It is further clear that such preconceptions often persist despite instruction on scientific theories which contradict them. The discrepancies between the students' post instruction conceptions and the scientific theories as taught often represent important failures of instruction.

Viennot (1979) among others has argued that students' preconceptions persist in part because they have worked so well in the everyday world of students. That similar ideas have sometimes held sway among scientists for centuries is testimony to their explanatory power. Anderson and Smith (1983) described how preconceptions are often compatible with much of the student's experience of instruction. Thus, preconceptions are active competitors with scientific alternatives as organizing structures for students experience of instruction as well as for their everyday experience.

The existence and persistence of students preconceptions implies that learning involves not simply the acquisition or formation of new concepts. It involves the *modification* of existing concepts or their replacement with appropriate alternatives, i.e., conceptual change (Toulmin, 1972).

Several researchers have proposed models of conceptual change. Posner, Strike, Hewson and Gertzog (1982) propose four conditions that must be fulfilled if accommodation* is likely to occur, that is, if students are to make changes in their

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*Both Posner, et al., (1982) and Nussbaum and Novick (1982a,b) use the term accommodation to refer to instances where students central conceptions undergo change in contrast to instances in which new information is incorporated with existing conceptions with little change (assimilation).

central concepts"

1) There must be dissatisfaction with existing conceptions.

2) A new conception must be intelligible.

3) A new conception must be initially plausible.

4) A new conception should appear fruitful (lead to new insights and discoveries)

Nussbaum and Novick (1982 a,b) describe a general teaching strategy for use where significant accommodation is expected.

1. Initial exposure of students' alternative conceptions through their responses to an "exposing event;"
2. Sharpening student awareness of their own and other students' alternative conceptions, through discussion and debate;
3. Creating conceptual conflict by having the students attempt to explain a discrepant event;
4. Encouraging and guiding cognitive accommodation and the invention of a new conceptual model consistent with the accepted scientific conception.

In one study Nussbaum and Novick (1982b) applied their model to the development and assessment of an instructional strategy designed to promote specific changes in sixth grade students' conceptions of the nature of gases. The authors reported that the strategy was "highly efficient in creating cognitive challenge and motivation for learning," but "did not lead to the desired total conceptual change in all students." In fact only one of the seventeen students was reported to have adopted the intended goal conception. The others ended up with one of five conceptions the investigators identified as intermediate between the students' original preconception and the goal conception. Another five students progressed as far as the last intermediate conception. The remaining students, about two-thirds, completed instruction with several misconceptions. The major conclusion drawn by the authors was "that a major conceptual change does not occur, even with good instruction, through revolution but is by nature an evolutionary process."

The present paper reports results of a study in which we analyzed the changes that did (and did not) occur in the conceptions of a class of fifth-grade students as they experienced instruction designed to change their conceptions of how green plants get their food. The instruction was based on Chapters 3-6 of the Rand McNally SCIIS Communities unit (Knott, Lawson, Karplus, Thier and Montgomery, 1978). This sequence incorporates elements of the conceptual change models summarized above.

The impact of instruction on students in our study was similar to that reported by Nussbaum and Novick (1982b). Following instruction only one student appeared to hold the intended goal conception with the others retaining their preconceptions or various hybrid conceptions. Similar results were obtained with a larger sample in a related study (Roth, Smith and Anderson, 1983). Since the goal of the instruction was by-and-large unfulfilled, the focus of our analysis has been on what went wrong.

While our results are consistent with those reported by Nussbaum and Novick (1983b), there seemed to be another story in our study, one concerned with ways that instruction seemed to go wrong where it might have been otherwise. Among these were:

- Students were often uncertain about empirical generalizations important to the strategy.
- Communication was sometimes hampered by systematic sources of ambiguities.
- The instruction was in some ways attacking the wrong preconception.
- Some important issues were not adequately framed through use of appropriate questions.

While these problems may not have occurred in Nussbaum and Novick's study, it is important to consider carefully the adequacy of instruction and of the particular instructional strategy in making judgments about a generic strategy and its theoretical base.

A detailed report of our analysis is beyond the scope of this paper. Rather we will present here a discussion of some ways teaching for conceptual change can go wrong with illustrations from the study, and discuss their implications for analysis and interpretation of empirical studies of conceptual change. As background, a description of the strategy for the instructional sequence is presented next.

Instructional Strategy

In the introduction we asserted that the sequence from the SCIIS Communities Unit was a conceptual change strategy. This assertion is based in part on the authors' explicit definition and discussion of the SCIIS Learning Cycle but also on our interpretation of the specific teaching suggestions in the <u>Communities</u> teacher guide (Knott et al., 1978).

<u>The SCIIS Learning Cycle</u>

According to the teacher's guide, the SCIIS curriculum is organized around a "learning cycle" consisting of three phases: exploration, invention and discovery. <u>Exploration</u> is characterized as involving students in "spontaneous handling and experimenting with objects to see what happens." The guide points out that "the materials have been carefully chosen to provide a background for certain questions the children have not asked before." It further notes, "During exploration activities you have the opportunity to observe the children and draw conclusions about their existing ideas and understandings" (Ibid, p. xviii). This implies that the exploration phase includes something like the "exposing events." The guide's description of the Learning Cycle does not mention anything like Nussbaum and Novick's "discrepant events", but as will be seen below, the strategy for the sequence under investigation does include and make use of such events.

The second phase of the SCIIS Learning Cycle is <u>invention</u>. This is the introduction by the teacher of a new concept as an alternative to the "preconceptions" which limit students "spontaneous learning." The teacher 'will have to provide definitions and terms as new concepts arise. This constitutes the "invention."'(Knott, et al., 1978, p. xviii). Further insight into the intended nature of the "invention" is provided in an article coauthored by the director of the original SCIS project, Robert Karplus, (Atkin and Karplus, 1962). While students are viewed as able to "invent concepts readily," they are not viewed as likely to be "able to invent the modern scientific concepts..." thus "it is necessary for the teachers to introduce them" (Ibid, p. 47). The authors related this idea to the view that science itself progresses through the invention of new concepts which are not only more powerful and useful, but which change the meaning and interpretation of observations. Thomas Khun's classic articulation of this view (1962) was cited in the article.

Following the invention of a new concept comes the discovery stage. It is important to note that it is not the new concept which is discovered, that is what is invented (i.e., presented by the teacher). Rather, this stage consists of "...activities in which a child finds a new application of a concept through experience" (Knott, et al., 1978, p. xviii). The students have opportunities "to discover that new observations can also be interpreted by using (the new) concept" (Atkin and Karplus, 1962, p. 47). Such activities "strengthen the concept and expand its meaning" (Knott, et al., 1978, p. xviii). They are "essential, if a concept is to be used with increasing refinement and precision" (Atkin and Karplus, 1962, p. 47).

The Instructional Sequence: SCIIS Chapters 3-6

The SCIIS Learning Cycle is designed to move students from preconceptions to new, more scientific concepts and can, therefore, be characterized as a conceptual change strategy. Further, the four-chapter sequence on which our research has focused includes elements similar to the exposing and discrepant events emphasized by Nussbaum and Novick (1982a,b).

The instructional sequence consists of four chapters (3-6) from the SCIIS Communities unit and represents about six weeks of instruction with about three lessons per week. The strategy for the unit is represented in Table 1 as a series of questions, anticipated empirical results of student investigations, and teacher presentations. The

TABLE 1

SUMMARY OF THE STRATEGY FOR CHAPTERS 3-6 OF SCIIS *COMMUNITIES*

Anticipated Preconceptions	Strategy Elements: Framing Question	Empirical Results	Presented Information	Intended New Conceptions
	Exploration Phase of the Learning Cycle			
	Chapter 3: Looking at Seeds			
	1. What is inside seeds?	Bean seeds have a small, plant-like part inside two large halves and a skin.	The small plant-like part is the "embryo," the two halves are "cotyledons."	Seeds have a small, plant-like part--the embryo--and larger part(s) the cotyledons.
	2. What do the embryo and cotyledon do for the growing plant?			
	Chapter 4: What Seed Parts Develop and Grow			
Plants take in their food from the soil. Water, fertilizer and minerals are food for plants.	3. Which seed parts develop and grow? What do you think each part of the seed does?	Bean embryos develop into plants only when attached to a cotyledon.		
	4. Why did the cotyledon and embryo live when joined?			
	5. Why didn't the cotyledon or embryo grow alone?			
	6. What do the embryo and cotyledon do for the plant?			The embryo develops into a new plant. The embryo develops into a plant only if it is attached to a cotyledon. The cotyledon provides food for the embryo.

TABLE 1 (Continued)

SUMMARY OF THE STRATEGY FOR CHAPTERS 3-6 OF SCIIS COMMUNITIES

Anticipated Preconceptions	Framing Question	Empirical Results	Presented Information	Intended New Conceptions
	Chapter 5: Do Plants Need Light to Grow?			
Plants need light to live and grow.	7. Do plants need light to grow? When?			
		Grass begins to grow in the dark and in light.		
	8. Why are the plants in the dark growing so well?			Plants do not need light to begin to grow.
	9. Which plants will survive better? Why?			Plants get food from their seeds (cotyledons)
	10. What does light do for plants?	Grass continues to grow in the light but not in the dark.		
	11. Why did the plants grow in the dark for awhile?			Plants do need light to continue to grow.
	12. Where do plants get the food they need?			
	13. Why did the plants in the dark die and those in the light live when both had the same soil?			Plants do not get food from the soil.
	Invention Phase of the Learning Cycle			
	14. Can you explain the results using the idea of photosynthesis?		Plants use energy from light to make food from water and air.	Plants use light to make food out of water and air.

TABLE 1 (Continued)

SUMMARY OF THE STRATEGY FOR CHAPTERS 3-6 OF SCIIS *COMMUNITIES*

Anticipated Preconceptions	Strategy Elements: Framing Question	Strategy Elements: Empirical Results	Strategy Elements: Presented Information	Intended New Conceptions
	Discovery Phase of Learning Cycle			
	Chapter 6: Cotyledons			
	15. What do you think will happen to young bean plants with and without cotyledons placed in the light and dark, respectively. Explain your reasons.			
		Bean plants without cotyledons grow in light, but die in the dark.		
		Bean plants with cotyledons continue to grow in light, but stop growing in dark after the cotyledons shrivel and fall off.		
	16. Which grew better--plants with or without cotyledons?			
	17. How well did plants without cotyledons grow in the dark? In the light?			
	18. What do you think the cotyledons do for a young plant?			The cotyledon provides food for young plants. After the food from the cotyledon is gone, plants need light to make their food.
	19. When do plants need light?			

major presentation is the invention of the concept of photosynthesis at the end of Chapter 5.

The questions included in the strategy serve several functions, some of which are not readily apparent. The SCIIS teacher's guide does not usually make such information explicit. Our interpretation of these functions are based on observations in thirteen classrooms including instances where the questions have been asked, modified and omitted (Smith and Anderson, 1983). Their functions include:

- encouraging student thinking and exploring their preconceptions about certain phenomena or topics
- establishing the purpose of an empirical investigation
- guiding student thinking about the interpretation of results
- establishing certain issues (rather than others) as the focus of attention
- providing opportunity to apply previously developed concepts and propositions
- confronting students with results which are not easily explained in terms of their anticipated preconceptions (i.e., to make students aware of a discrepant event)
- driving student thinking to consider the underlying explanation for empirical results.

Although not initially apparent, the underlying issue for the sequence is the source of food for plants. Following the student's introduction to the parts of the bean seeds in Chapter 3, Question 2 raises the issue of the function of the seed parts. This focus, carried on through Chapter 4, is crucial since the cotyledon's function of providing food to the embryo is intended to lead into the central, underlying issue of the source of food for plants. Raised again in Question 6 this issue leads the interpretation of the investigation in Chapter 4 beyond the essentially empirical generalization that the cotyledon and embryo need each other for a new plant to grow with which the discussion might otherwise conclude.

Questions 7 and 12 are important in exposing students' preconceptions about the relationship of light to plant growth and the sources of food for plants, respectively. Question 13 is the point at which the anticipated student preconception that plants get their food from the soil is to be confronted with the discrepancy of plants dying in the dark despite the presence of rich soil. This concludes the exploration phase of the sequence.

Following the invention of photosynthesis as an alternative conception of plants source of food, Question 14 leads to the application of the new concept in explaining the results obtained. Chapter 6 is the discovery phase of the sequence in which the concept of photosynthesis and the food supplying function of the cotyledon are to be applied in predicting and explaining continued growth of bean seedlings with cotyledons removed and left on under conditions of light and darkness, respectively.

Overview of the Study

In many respects the study was similar to that of Nussbaum and Novick (1982b). It was a case study of the use of a particular teaching strategy with a single class of fifth-graders. Our data sources included pre and posttest responses for all students, interviews of target students at five different points, observation notes and narrative descriptions of instruction, tape recordings of all lessons, and transcripts of selected class discussions. One difference was that, in our study, the teacher was an experienced elementary teacher teaching her own students without direct input from the researchers. She was teaching the sequence for the third year, this time using a teacher's guide developed in a related study (Smith and Anderson, 1983) and designed to make the conceptual change strategy more explicit.

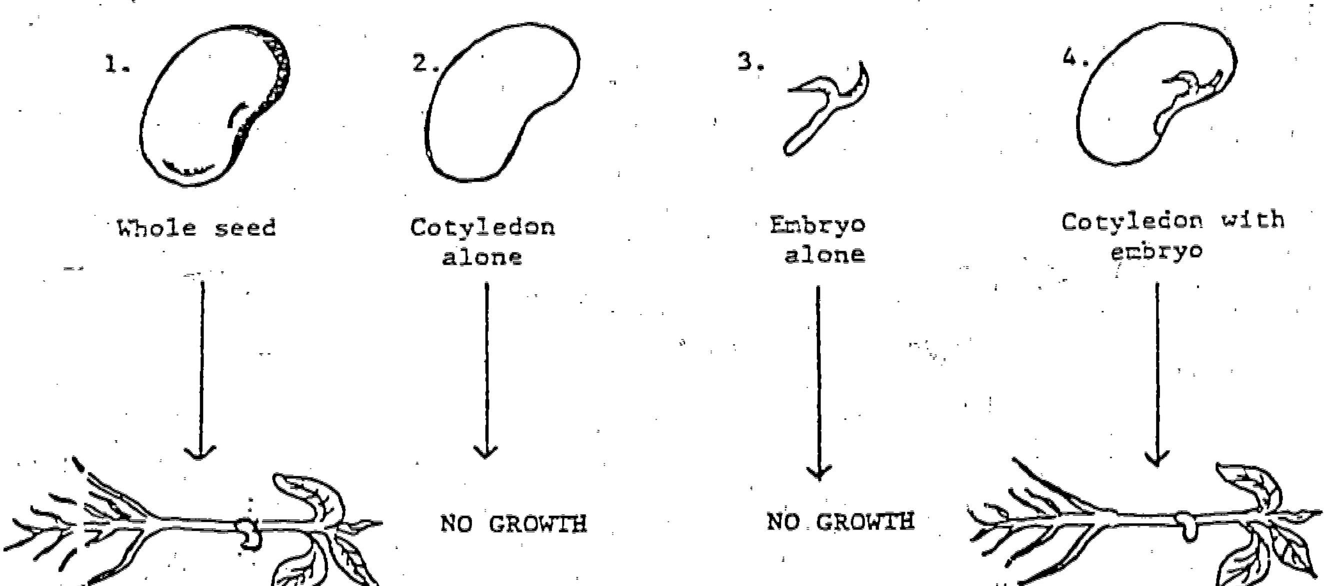
As stated above, the instruction was not very successful in bringing about the intended conceptual changes. About seventy percent of the students incorporated into their coneptions the idea that a plants make food. However, less then twenty percent of them clearly related this to the availability of light. Furthermore, plants making of food was not adopted as an alternative to taking in food from the environment. Rather it was viewed as an additional source. Thus, these propositions tended to be assimilated into the students' preconceptions of what constitutes food for plants with relatively little basic change in those preconceptions. Only one student appeared to have accommodated to the goal conception.

The contrast between these results and the reasonableness of the SCIIS strategy led us to examine the issue of what went wrong. We were led to a number of problems that appear to have general implications for cognitive instruction.

Ways of Going Wrong

Empirical Ambiguity

The instructional strategy depends on certain empirical generalizations. For example, Chapter 4 addresses the issue of the functions of parts of seeds and involves an experiment in which the students attempt to germinate four different combinations of bean seed parts as shown below:



Development of ideas about seed part functions uses the generalization that the embryo develops into a plant only if attached to a cotyledon. This generalization in turn rests on the anticipated results that neither the isolated embryo nor the isolated cotyledons grow, while the embryos with one cotyledon attached and the whole seeds do grow as illustrated. From the standpoint of a trained adult these trends were clear in the students' results. However, making the intended empirical generalization was not a straightforward matter for many of the students.

Two sources of difficulty relate to aspects of what Strike and Posner (1982) refer to as the students' conceptual ecology namely their implicit measurement and observation theories. First, some of the students attended primarily to their own individual set up, ignoring other instances. Their implicit assumption seems to have been that one case is sufficient and agreement among multiple instances is irrelevant. Thus, atypical results obtained by some groups were generalized even when the trend across groups was clearly in the opposite direction.

For example, in some instances the whole seeds did not germinate. The following excerpt from an interview of one of the target students following completion of Chapter 4 illustrates:

I: What did you think about the whole seed?

S: O.K., it went to 18 millimeters, and 19, 19, 20, 20. I don't know what happened. Well, the whole seed has everything right but it just didn't grow that much.

I: Do you think that some other whole seeds would grow or don't you think that any of the whole seeds grow?

S: I think that maybe some of them would. I don't know.

I: Did some of the other students' whole seeds grow?

M: I don't think so....

This is surprising because, as she implied, this result is somewhat counter intuitive. Furthermore, she had just correctly explained the meaning of points on the class chart which had color coded dots showing that some of the whole seeds had indeed grown substantially. Apparently, she had not felt it necessary or important to consider the other groups' results. Another indication of this assumption was students referring to atypical individual points on the class graph, rather than to some more central or representativ point.

A second aspect of students' implicit observation theories that came into play was judging the significance of differences in the measurements. How much change in the length of the isolated embryo, for example, constitutes "growth". Some of these embryos did grow a few millimeters in length. In comparison to those attached to the cotyledons, however, this growth would generally be considered by our trained adults as negligible. On several occasions, however, students apparently did not apply the negligibility principle and reported that their isolated embryos "grew".

Some of these problems might have been overcome had the teacher put more emphasis on the class graph. That is, she might have pressed the students toward an alternative observation theory. However, the somewhat cumbersome procedure suggested for estimating, recording and connecting average points for each observation of each experimental condition was carried out for only some of the data. The combination of the relatively large amount of time and effort involved and the apparent greater meaningfulness to the students of actual example germination systems led her to deemphasize use of the class graph. Given the nature of the students implicit observation theories, this appears to have contributed to the students continuing to use their original observation theories and the resulting ambiguity in the students' thinking concerning the empirical results.

Ambiguity in Discourse

The ambiguity just discussed in regard to empirical results may tend to arise to some degree in any instruction which relies on first hand inquiry. However, systematic ambiguity can also occur in classroom discourse. In the present case, such an ambiguity exacerbated the empirical ambiguity in Chapter 4. It arose from the possible alternative referents for the terms 'embryo' and 'cotyledon'.

The issue underlying the investigation was the function of the embryo and cotyledon as parts of a seed. However, the experiment was set up so that an isolated embryo and an isolated cotyledon were experimental conditions as well. Thus, the question, "Does the embryo grow?" is ambiguous. While the isolated embryo conditions did not grow, the embryos as parts attached to cotyledons did grow. Since the function of the embryo as the part that grows is a central issue, there were many opportunities for confusion during class discussions.

Similarly, an important observation made by one of the students and emphasized by the teacher was that the cotyledon (part) was shriveling or shrinking as the attached embryos grew. This was very suggestive of the cotyledon somehow being used up. However, some of the students interpreted these reports as referring to the isolated cotyledon (condition) and tended to disagree. In the process they did not attend to and have the benefit of this important but subtle observation.

Attacking the Wrong Preconception

The SCIS instructional strategy anticipates that students will hold a preconception concerning the source of food for plants, namely that plants get their food from the soil. The teacher's guide also indicates that for the students this "food" is water and fertilizer or minerals, but this is not attacked directly. The point is made that bean seeds in Chapter 4 were germinated without soil and there is an optional activity of growing seeds without soil. The point of exploring the functions of the parts of the seed in Chapter 4 is primarily to provide an alternative conception of the source and nature of food for young plants, the part of the seed referred to as the cotyledon. Finally, the key discrepant event built into the sequence is the determination in Chapter 5 that grass plants survive in the light but not in the dark, even though both conditions had the same soil.

While the idea that plants get their food from the soil was common among students in the study, this does not seem to be the core of their conception. The central preconception also seems to be deeper than the idea that water and fertilizer or minerals are food for plants. Fundamentally, food for plants is conceived by the students as whatever materials are needed and taken in by the plants. Furthermore, their notion of food is additive. If the plants are unable to get certain materials from the soil, other materials such as air and even light may be considered as adequate alternatives.

Given the additive conception of food for plants as whatever materials the plants take in, the students could simply add the cotyledon as another source of food rather than add an alternative to what constitutes food. Some of the students saw the cotyledon as an "extra" source of water or fertilizer.

Another consequence of this underlying conception of food for plants was that the students easily escaped the trap represented by the intended discrepant event. Light was simply added as an essential component of plants' food. This preconception also tended to promote what Hewson (1980) calls "conceptual capture" of the concept of photosynthesis when it was invented. Photosynthesis was assimilated to this conception as a process in which light, water and air were mixed together but each substance maintained its own identity. Other students interpreted photosynthesis as the name for this mixture. Asked in Chapter 6 why she thought the bean plants in the dark would continue to grow, a student explained that photosynthesis was light, water and air and that "two out of three isn't bad."

Thus, because the strategy failed to address the students' underlying preconception, few students came to understand photosynthesis as a process in which food is made out of light, water, and air. Even fewer students understood that green plants have no other source of food.

Loose Framing of Important Issues

Many steps in the instructional strategy take the form of questions as reflected in Table 1. In a number of instances we observed problems that could have been lessened by more appropriate use of questions in framing the issues. For example, in Chapter 4 the students appeared to have considerable difficulty relating the empirical results of the investigation to the issue of the function of the seed parts. While part of the problem was probably the uncertainty of the students concerning the empirical results discussed above, another factor was the pattern of questions used to frame the investigation and the interpretation of results. The strategy suggests introducing the investigation with a discussion of the students' ideas about the seed part functions. However, it includes no question requiring the students to use those ideas in predicting what might happen in the germination experiment. In actual instruction, no question which would drive students' thinking to consider the relationship between the results and the students' ideas about the seed parts functions was posed prior to the last two lessons.

When the issue of the relationship between the results and the students' ideas about the seed parts functions was raised in lesson 5, the questions in terms of which it was framed appeared to be inadequate. The teacher first asked the students what they thought the parts' functions were. She then asked for "evidence" to support their views. However, the students' ideas about what would constitute evidence were such that they did not usually see this question as pointing them toward the results of the experiment. Fewer than a quarter of the responses to the teacher's request for evidence in support of the students' views about the seed part functions drew on the results for the four conditions in the experiment. Thus, the question did not appear to match the student's notion of what constitutes evidence.

Given the nature of the students' preconceptions about what constitutes evidence, a question which more tightly structures the students' thinking about the relationship between the experimental results and their ideas about the functions was warranted. In this instance the teacher had not used the questions that had been suggested in the strategy (Questions 4, 5 and 6). In this instance the questions suggested in the strategy do appear to more adequately frame the issue. They first articulate aspects of the results and then require the students to explain why these results were obtained.

Our analysis indicates that the selection of questions is a very crucial aspect of an instructional strategy. In some cases there appeared to be important gaps in the strategy or questions which were not adequate to the situation. In other instances the teacher did not use questions provided in the strategy that appeared superior to the ones actually used. In still other instances the teacher used the indicated question but failed to recognize when student responses indicated predictable alternative conceptions on the part of the student. Such conceptions include the students' implicit observation theories and explantory ideals, elements of what Strike and Posner refer to as the students' "conceptual ecology".

Discussion

The problems we have illustrated indicate that matching instruction to the conceptual ecology of the students is both essential and difficult. Developers must be aware of predictable alternative conceptions and identify appropriate questions and other moves accordingly. Teachers must also be aware of the alternative conceptions and the intended roles of specific questions so that they can recognize indications of students' alternative conceptions and respond appropriately.

The heavy information processing load that this role places on the teacher suggests the importance of incorporating such information into instructional materials. This is not to make the materials teacher proof but rather teachable. Given the best of strategies, the teacher plays a crucial role in the diagnostic use of appropriate questions, in the interpreting of students' responses and taking appropriate actions. In our own work we are exploring the use of text materials (Roth, 1983) and overhead transparencies (Anderson and Smith, 1983) to assist the teacher in appropriate use of diagnosticly and strategicly important questions.

The value of a generic strategy such as Nussbaum and Novick's or the SCIIS learning cycle lies in its prescriptive power. To the degree that it is consistent with the real world of teaching and learning, its use in developing curriculum and planning instruction increases the likelihood that students will learn as intended. While particular strategies might be developed and assessed independently of any explicit generic strategy, the generalizability of such efforts is limited.

While a generic strategy must be sound if its use is to result in effective instruction, a sound generic strategy is not sufficient. A particular strategy may not be an accurate instantiation of the generic strategy or the instruction may not actually implement the strategy. Apart from the issue of fidelity, the particular strategy or instruction may be inadequate in ways that have nothing to do with the adequacy of the generic strategy itself. The examples presented in this paper reflect all four of these possibilities. The models of Strike and Posner (1982) and Hewson (1981) helped identify and interpret these examples and point to other aspects of students conceptual ecology which might be problematic.

In their conclusions,(Nussbaum and Novick, 1982) state:

> In our opinion, the state of the art in cognitive education does not at present offer a widely accepted theory base which could easily facilitate the design of instruction for learning many basic conceptual schemes in school science. p. 20.

While problems such as those described above may not have occured in their study, it is important to consider other levels of going wrong in assessing a generic strategy and its theory base. Such an assessment should probably be based on productivity over time rather than on the success or failure of a single attempt to apply it. While we would not dispute Nussbaum and Novick's statement, we do think that the currently available theory base does provide an important foundation for ongoing development and research.

Nussbaum and Novick (Ibid.) conclude with the following recommendation with which we heartily concur:

> That the growing community of practitioners who are looking at SAF's (Student Alternative Frameworks), extend their studies in the direction of designing and testing new instructional sequences based on principles of cognitive accommodation.

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