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Implementing Conceptual Change Teaching in Primary Science

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Abstract

A study was made of the extent to which 8 teachers in grades K–3 were able to implement a 2-week conceptual change science unit in their classrooms following a 4-week summer institute. The effects of the institute program, which was designed to help teachers develop the subject-matter and pedagogical knowledge needed to teach a unit on light and shadows, were assessed by analyzing (1) videotapes of lessons taught before and after the program, (2) interviews that measured students' understanding of light and shadows phenomena before and after the unit was taught, and (3) teachers' written evaluations of their units. 1 year later, teachers were interviewed about their continuing use of the unit and conceptual change teaching strategies generally. Results, which indicated that the 8 teachers were generally successful in implementing a conceptual change unit of their own on light and shadows and in changing students' conceptions, are discussed in relation to case methods and cognitive-apprenticeship models of training.

Interest in the use of teaching strategies that facilitate children's conceptual change has been growing (Eylon & Linn, 1988; Porter & Brophy, 1988). Such strategies focus on students' prior conceptions of the subject matter under study and seek to provide the conditions under which these preconceptions may be elicited and challenged so that students can construct more general, powerful, or "correct" conceptions (Anderson & Smith, 1985; Posner, Strike, Hewson, & Gertzog, 1982; Vosniadou & Brewer, 1987).

For example, in a science unit on light and shadows, a boy's conception that shadows are projected from the front of the body (DeVries, n.d.; Piaget, 1930) may be elicited by asking him to predict where his own shadow will fall as he turns his body in the

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sun. This preconception is challenged as the boy faces sideways to the sun while another student traces the shadow; to his surprise, the shadow appears at the boy's side, not at his front. Through making predictions, recording observations, giving explanations, and discussing with his peers, the boy may revise his conceptions toward the scientific view that shadows are produced not by some emanation from the body but by his body as an object that is blocking rays from a light source.

The present study explored the extent to which such conceptual change teaching strategies could be used successfully by primary teachers in science. Eight teachers (K–3) who had participated in a 4-week summer institute were studied as they implemented a conceptual change science unit in their own classrooms. The extent of their success was examined on the basis of videotapes of lessons, teachers' written evaluations, interviews with teachers, and subject-matter interviews conducted with children before and after the unit was taught.

Conceptual change teaching strategies are of particular interest because of widespread evidence that students bring their own ideas to the study of school science, and that these ideas are powerful determinants of what students gain from instruction (Driver & Erickson, 1983; Eaton, Anderson, & Smith, 1984; Jones, 1988). Furthermore, conventional science instruction often fails to address or to change misconceptions about physical phenomena that students bring with them to class (Eaton et al., 1984; Jones, 1988). Even good students who do well on course exams often continue to hold conceptions that are at variance with the scientific theories that they have studied (Carey, 1986; Champagne, Klopfer, & Anderson, 1980; Clement, 1983; Minstrell, 1984).

A difficult problem for those interested in conceptual change teaching is how to implement such teaching strategies in classrooms. How can conceptual change teaching be designed to fit the realities of schools? How can teachers be helped to develop the knowledge and skill needed for conceptual change teaching? And what school conditions encourage the implementation of these strategies?

Some guidance in answering these questions can be obtained from the general literature on school improvement and educational innovation. One lesson that has been learned is that the introduction of any new teaching practice is a complex and problematic process (Neale, Bailey, & Ross, 1981). Factors associated with successful implementation include such things as support from district and school administrators, acceptance by teachers, clear guidelines for use, timely training in skills needed for implementation, ongoing support from peers or coaches, and modifications of organizational constraints (see, e.g., Fullan, Bennett, & Rolheiser-Bennett, 1989; Fullan & Pomfret, 1977; Griffin, 1983; Hall & Hord, 1987). However, even the successful implementation of new practices may be short lived unless special institutional supports and incentives remain (Hord & Huling-Austin, 1986; Lieberman, 1986; Stallings & Krasavage, 1986). Thus, efforts to implement conceptual change teaching strategies must provide the kinds of substantial supports to teachers that have been recognized as needed for the implementation of new practices generally.

In addition to the general problems of implementing new practices, efforts to introduce conceptual change teaching in science must also overcome some special difficulties. First, such teaching calls for a thorough understanding of subject-matter knowledge, including knowledge of children's likely preconceptions and of representations of subject matter that students can grasp. Second, teachers must know how to identify students' misconceptions and know how to challenge misconceptions by providing discrepant events. Such processes place unusually heavy cognitive demands on teachers because unexpected events are frequent and call for rapid teacher decisions.

The teacher must simultaneously be concerned with subject matter, students' thinking, lesson structure, and classroom social behavior (Anderson & Smith, 1985; Neale, 1985; Smith, 1989). Third, in conceptual change teaching students are encouraged to test their predictions and explanations with experiments and observations, then to represent and discuss the results. Lessons often involve small-group activities and open-ended discussion. These are unfamiliar lesson structures for most teachers, who often encounter management problems when they use such activities (Anderson & Barufaldi, 1980; Smith & Sendelbach, 1982; Tobin & Fraser, 1987).

Some promising attempts to implement conceptual change teaching have been reported. After disappointing results with conventional teacher training techniques, Anderson and Smith (1983b) found that junior high teachers followed conceptual change strategies if provided with revised teachers' guides and overhead transparencies to use in eliciting specific student misconceptions (see also Smith & Anderson, 1984). A promising approach in mathematics (Carpenter, Fennema, Peterson, Chiang, & Loef, 1988) employed a summer course that provided teachers with extensive information about the development of children's mathematical concepts. Teachers then used this pedagogical-content knowledge (Shulman, 1986) to alter their teaching so that more emphasis was placed on conceptual understanding and children's own problem solving.

We have been exploring ways to encourage the use of conceptual change teaching strategies by primary science teachers. In the process, we have developed procedures that are based on a systematic analysis of the teacher knowledge needed to implement conceptual change teaching and that utilize a cognitive-apprenticeship approach to the acquisition of expertise.

Knowledge Underlying Teacher Expertise

With others who view teaching expertise as a complex cognitive process (Clark & Peterson, 1986), we believe that the design of teacher training activities should begin with an analysis of the knowledge needed for successful teaching. Although research on teacher cognition remains limited, recent research provides useful guidelines for specifying such knowledge.

Following Leinhardt and Greeno (1986), we believe that expert teaching requires well-developed procedural knowledge of lesson structures, including activity schemata, rules, routines, and information schemata. Furthermore, teachers need appropriate subject-matter knowledge that they can use with purpose and flexibility within lesson structures (Leinhardt & Smith, 1985). Such subject-matter knowledge includes substantive knowledge, pedagogical-content knowledge, and knowledge of curriculum in relation to the subject matter being taught (Shulman, 1986). Finally, teachers' beliefs about subject matter and how it should be learned play an important role (Anderson & Smith, 1985). Thus we designed our work with teachers on the basis of a systematic analysis of both pedagogical knowledge (i.e., lesson structures) and content knowledge (including pedagogical-content knowledge and beliefs) needed by an expert who was using conceptual change strategies in grades K–3 science classes (Neale, 1985).

Cognitive Apprenticeship

If an analysis of teacher knowledge is taken as a point of departure, then teacher training may be understood as a process through which teachers may construct the knowledge underlying expertise. Not only must teachers acquire various elements of knowledge, but they must also combine these elements in flexible, articulated structures that they can access with little effort (Berliner, 1986). Even though they may be expert in using conventional teaching strategies, when implementing new strategies teachers may resemble novices and may have to go through a number of stages to acquire full expertise (Hall & Hord, 1987).

A promising way to assist novices in acquiring expertise is through the process of cognitive apprenticeship (Collins, Brown, & Newman, 1989). As in the historic apprentice relationship, a master models expert performance and assists as novices undertake a series of tasks, graded in difficulty, that require increasing expertise. The graded tasks and the assistance represent scaffolding that is gradually removed as apprentices acquire expertise (Gott, 1988).

In the present case, modeling was provided in the form of a demonstration unit on light and shadows, videotapes of an expert teacher, and the use of conceptual change strategies by an instructor during training. Scaffolding was provided by limiting the focus of training to a restricted subject-matter domain, by using small groups and trial teaching, and by providing coaching as teachers planned and taught a conceptual change unit in their own classrooms.

It should be noted that, from the perspective of cognitive apprenticeship, the modeling and scaffolding provided were just a small step toward expertise. Other steps that either have been or could be taken by teachers include: (*a*) reteaching the unit on light and shadows, (*b*) teaching other prepared science units, (*c*) using new teaching strategies in other subjects, and (*d*) developing new conceptual change units.

Method

Demonstration Unit

Prior to the design of activities to be used with teachers, a demonstration unit was developed to exemplify the principles of conceptual change teaching in primary science classrooms. Based on a survey of related research, the following characteristics of conceptual change teaching were identified (see Smith & Johns, 1985).

1. Instruction is directed toward the contradiction of significant, general schemes or mental representations that children have about natural phenomena and toward the development of more powerful, scientifically accurate models.
2. Instructional episodes are linked conceptually to prior lessons and to children's informal experiences during reviews, presentations, activities, demonstrations, discussions, and summaries.
3. Instruction elicits children's conceptions of natural phenomena through their predictions and explanations about phenomena.
4. Activities are provided in which children test their predictions, discover contradictory evidence, and contrast alternative explanations and conceptions, including appropriate scientific models. Materials and activities are simple and focus on immediate results, which can be varied by the children.
5. Children represent their own thinking in several modes (e.g., writing, speaking, drawing, graphing), and the teacher checks their understanding of these representations. Children share the results with the teacher and each other and are encouraged to debate each other.
6. The teacher helps children summarize experiences, highlights and contrasts alternative views, and requests explanations that examine the evidence available to support each. Results are then related to prior and future lessons, and applications in children's lives are generated and tested.

These characteristics were used to revise an earlier Elementary Science Study unit on light and shadows (Morrison, 1968). The revised unit was designed to address common misconceptions that children have about light and shadows (see Table 1) and provided activities and discussions so that children could construct the following scientific content:

Light travels in straight lines in all directions from the source.

Shadows are places where light has been prevented from traveling (e.g., by being absorbed, reflected, or refracted).

For example, children sometimes think that a person's shadow is a concrete entity

TABLE 1. Targeted Pedagogical Content Knowledge of Children's Misconceptions about Light and Shadows

Source	Children's Misconceptions
Guesne (1985)	1. Light is the same as its sources, for example, a light bulb, the sun.
Anderson & Smith (1983a); Guesne (1985)	2. Light is bright, static "stuff" that stays in one place or hangs in the air.
DeVries (n.d.); Guesne (1985)	3. Light illuminates or brightens.
Piaget & Garcia (1974)	4. Light travels in a straight tunnel from its source; as the distance between the source and the surface is increased, children expect the diameter of the light on the surface to decrease.
DeVries (n.d.); Piaget (1930)	5. A shadow is a concrete or tangible thing.
Piaget (1930)	6. A shadow is a projection or emanation from the body.
DeVries (n.d.); Piaget (1930)	7. A shadow is pushed out or forced out by the light.
DeVries (n.d.)	8. A shadow's location depends on where the person or object is looking or facing or leaning, or the proximity of the object to the location.
DeVries (n.d.); Guesne (1985)	9. A shadow is a reflection of the object.
Inhelder & Piaget (1958); Siegler (1981)	10. The size of the shadow depends only on the size of the object.
DeVries (n.d.); Piaget (1930)	11. Two objects will each make a separate shadow even if one is in the shadow of the other; a shadow can be present at night in the darkness.

that comes out of the "front" of the body (where the face is). In the unit, children went outside to trace their shadows on the sidewalks. They first faced away from the sun, so that the shadow did come out the "front" of their bodies. Then, they faced to one side, so that their ideas that shadows were projections from the body would be contradicted by the location of their shadows. When children returned inside, the class discussed why the shadow's location did not move when they turned their bodies. In a subsequent lesson, they moved dolls in various positions around a light, predicted where the shadows would be, then turned the light on and recorded where the shadows actually appeared. These tracings were also presented and discussed in the whole-group meeting.

Analysis of Expertise

The 13-day unit was taught by an expert teacher to several classes of children in grades K–3 in a college of education laboratory classroom. On one such occasion, extensive records were made of the planning and teaching of the unit, including pre- and posttests of children's thinking, audio recordings of planning sessions, videotapes of each class session, and recordings of stimulated recall interviews with the teacher (for details, see Neale, 1985; Smith & Johns, 1985).

These data were used to describe and document the subject-matter and pedagogical knowledge required for successful teaching of the unit. Subject-matter knowledge was specified in categories suggested by Shulman (1986), including substantive, syntactic, and pedagogical-content knowledge (Smith & Neale, 1989). Pedagogical knowledge was analyzed, following Leinhardt and Greeno (1986), in terms of activity schemata, rules and routines, and information schemata (Neale, Smith, & Wier, 1987). The results of these analyses may be considered as an example of case knowledge (Shulman, 1986), which was then incorporated into the program with teachers. The purpose of such case knowledge is to communicate principled knowledge about teaching, in this instance propositional knowledge of the principles of conceptual change teaching, as well as procedural knowledge for their implementation.

Subjects

Ten teachers from grades K–3 (two kindergarten, six first grade and two third grade) were recruited to participate in a federally funded institute on primary science instruction. Following announcements that were mailed to 47 schools, 10 teachers completed formal application procedures, which included a recommendation from the principal or supervisor. Applicants were observed while teaching to screen out those who might be weak in teaching skills generally and therefore unlikely to benefit from the institute. Two teachers had been involved with the laboratory classroom in the preceding academic year. All were experienced teachers (5–27 years), and all except one were female. For confidentiality, all subjects were given pseudonyms in this article. They were teaching in nine schools in three districts.

Teachers' classes ranged in size from 21–28. All classes were heterogeneous in composition. Ethnic composition ranged from 25%–42% minority. Ability levels ranged from 14–90 (Normal Curve Equivalent) on the reading section of the California Test of Basic Skills. (CTBS scores were not available for the kindergarten classes.)

Summer Institute

The first phase of training occurred in a 4-week summer institute funded by the Education for Economic Security Act, Title II. The instructor was a science educator and experienced primary teacher who had developed and piloted the demonstration unit. Teachers were paid a stipend through their districts and received four graduate credits for the summer program. Before the institute began, we asked teachers if we could videotape them teaching a science lesson in their classrooms. Teachers were also interviewed. The interview, which was conducted by the institute instructor, assessed the teachers' knowledge and beliefs about science and science teaching generally, about the physics of light and shadows, about children's knowledge of light and shadows, and about how one would best teach children this content. Videotapes and interview results were examined to identify each participant's knowledge and skill with regard to the objectives of training (see Smith & Neale, 1989, for details).

During the first week of the institute, teachers read and discussed research on children's misconceptions and on teaching strategies that facilitate conceptual change. Readings were chosen to provide evidence that contradicted teachers' views. Then teachers conducted interviews about light and shadows with children who were part of a summer science camp associated with the institute. The purpose was to sensitize teachers to student conceptions and how to elicit them.

Teachers also tested their own knowledge of light and shadows in activities that revealed their misconceptions and provided opportunities for them to construct more adequate conceptions. The activities for both the teachers and the campers were designed to model procedures of conceptual change teaching. Lessons usually began with a problem or puzzle to explain; proceeded to predictions, explanations, and debate; led to small-group inquiries where data were collected and represented by writing, graphing, or tracing; and ended with discussion of results in relation to original ideas.

During the second and third weeks, teachers taught light and shadows content to small groups of summer campers, ages 5–8, in the morning. Two teachers were responsible for each group. One taught while the other coached, with the teachers reversing roles during the third week.

In the lessons, teachers generally moved through several lesson segments. An opening meeting with the group served as a review of previous lessons and as a source of information about children's thinking. This discussion usually moved into the teacher's presentation of a related puzzle or problem to be solved, with children giving their predictions and explanations for what they thought would happen. Next, children moved into small groups of three or four for activities. They manipulated materials to produce effects and recorded their results in some way (tracing, graphs, writing, pictures). Finally, in the concluding meeting, children reported their results and compared them across groups, discussed anomalies, and considered further questions to be solved.

Each teacher was videotaped at least once, with the videotape becoming the subject of discussion in the afternoon (teacher and coach present; others welcome). Afternoons were also used for further exploration of light and shadow activities, discussion of issues raised by morning sessions, and preparations for the next day's teaching. The purpose of the small-group teaching was to provide a safe opportunity, with limited cognitive demands and plenty of scaffolding, for teachers to begin to construct the knowledge needed for teaching a conceptual change unit in their own classrooms. Teachers made regular entries in logs to help them reflect on their experiences.

In the final week of the institute, teachers interviewed children again about light and shadows content to assess the progress they had made at the camp. Then teachers met in grade-level teams to discuss plans for a 2-week unit each would teach in her classroom during the coming year. Finally, with consultation from the institute instructor, teachers developed preliminary plans for teaching their units.

Although teachers generally addressed the common misconceptions found at their grade levels and designed activities to help children construct scientific ideas about light and shadows as in the demonstration unit, there were differences across grades in tasks that addressed similar ideas. For example, the kindergarten teachers' plans included an activity in which children took wooden blocks outside to construct castles and traced the outline of their castles' shadows on paper laid on the sidewalk next to them. As children worked, teachers planned to talk with them about various openings—windows and doors—that appeared in their shadows and about how those showed up. Their intention was to focus children's attention on the direction of the sunlight and where it traveled through the castle openings and where it did not. For kindergarten children, simply noticing the direction and travel of the light was an important step.

A third-grade teacher planned an activity in which children also constructed castles, with one important requirement: they were to figure out a way for light to go through three windows in the middle and two ends of a wall of the castle when the light was turned on. This task was designed to provide evidence that contradicted the children's common idea that light travels straight ahead in a tunnel from the source (instead of diverging in all directions). When children turned on the light, they would be surprised that the light went not only through the middle window, but also in a thin sliver through the end windows. Their tracings of where the light did go through, for the three windows, would provide the evidence for a discussion of the direction and travel of the light. So, although children at both grade levels would build castles and talk about the direction of light's travel, the two tasks differed in important ways depending on the children's current understanding.

Academic-Year Activities

The second phase of training was a follow-up program during the academic year. Monthly teacher meetings were held to continue reading and thinking about the physics of light and shadows, about the principles of conceptual change teaching, and about the translation of principles into plans for an instructional unit. Preliminary plans that had been developed during the summer were revised based on feedback from the instructor and peers; the instructor also met with each teacher for two 3-hour planning sessions prior to the unit that was taught. Units were scheduled so that the instructor could monitor, videotape, and give feedback on each teacher's unit as it was being taught. After at least four of the 10-unit lessons, the institute instructor coached the teacher, giving encouragement and suggestions about next steps. Teachers kept journals of their experiences. The present study investigated how successfully the teachers who were involved in such training were able to implement a conceptual change unit on light and shadows in their own classrooms.

Data Analysis

Some of the data about changes in teacher knowledge are reported elsewhere (Smith, 1987, 1989; Smith & Neale, 1989). The present article focuses on how successful the teachers were in implementing the conceptual change units in their own classrooms and the extent to which teachers implemented conceptual change strategies both in other subjects and in the year that followed. Evidence about implementation came from an analysis of videotaped lessons before and after training, from interviews with students before and after the unit was taught, from teachers' own written self-evaluations, and from interviews with the teachers.

Analysis of videotapes was undertaken by constructing an innovation configurations checklist (Hall & Hord, 1987, chap. 5), which was used by a trained rater to rate lesson features in the lesson submitted prior to the summer institute and in the fourth and ninth lessons of the 10-lesson unit on light and shadows that teachers taught in their classrooms during phase 2 of the program. These lessons were selected because they occurred near the end of each week's teaching and sampled from different portions of the unit.

The configurations checklist was derived from observation procedures used by Hollon, Anderson, and Smith (1980) as adapted to our analysis of conceptual change teaching in primary science (Neale, 1987). Three levels of implementation were specified for each of 31 features of conceptual change teaching so that lessons could be rated on each feature as showing either (1) no implementation, (2) partial implementation, or (3) high implementation. High levels of implementation are defined for each feature in the Appendix.

The 31 features, which were grouped in six categories, included eight lesson segments that had been identified in the analysis of expert performance in the demonstration unit as well as indicators of the desirable features of conceptual change teaching given above.

Items on the configurations checklist were developed through a series of ratings of sample lessons chosen to represent both full and partial implementation. Ratings were made after inspecting a videotape recording and a printed transcript of each lesson. After appropriate training, raters achieved high interobserver agreement (.94–1.00 for pairs of raters on the 31 features).

Success in implementation was also examined by measuring children's conceptions of light and shadow phenomena both before and after teachers taught their versions of the light and shadows unit. A random sample of one-half of the children in each class, stratified by gender and ability (high, medium, and low according to teacher rating), was interviewed before and after the units. One third-grade class and one first-grade class were selected for intensive study, and all children in these classes were interviewed. Children were interviewed individually in a quiet setting by trained interviewers who were former elementary teachers. Children were shown materials (e.g., a doll and light) in different relationships. Then they were asked to predict what would happen if various manipulations were made and to explain why they thought that would happen.

The kindergarten children were given a briefer version of the interview, without more difficult questions on topics such as merged shadows and the divergence of light. First and third graders received a longer interview covering a broader range of topics.

For example, children were asked, "When it's night time, and you're in bed and all the lights are turned off, do you have a shadow?" to probe for the misconception that a shadow is a concrete entity that exists independently of the light. They were also asked about situations like the following. A doll is placed behind a tensor light with a shade, but facing the back of the light. The child was asked, "If we turned this light on, could you make a shadow with the doll here?" (pointing to the doll behind the light). This question probed for the child's misconception that the shadow is a part of the doll and projects from the front, in the direction the doll is facing.

Children's responses were scored by two trained research assistants (graduate students in measurement and evaluation), both for accuracy of predictions and for quality of explanations, and a total score was obtained to represent each child's understanding of unit concepts.

In the examples of questions given above, suppose a child said that her shadow was present at night and returned inside her body or was present but could not be seen because there was no light. Her answer would be scored as inaccurate in prediction (shadows are not present at night) and inadequate in explanation (shadows require light both to be made and to be seen; they are not like a tree, which is there whether light is available to see it or not). In contrast, the answer of a child who responded that her shadow was not there at night, in the darkness, because there was no light to be blocked to make it, would be scored as accurate and as providing an adequate explanation. Her reason refers explicitly to the action of light in making shadows and provides enough information to distinguish it from the common misconception that the light makes the shadow by pushing it out of the body.

In the second example, a child might respond that the doll behind the light will make a shadow when the light is turned on, because she is facing that way. This answer is inaccurate (no shadow will appear), and the explanation suggests that the shadow location is controlled by the position of the doll's face, a common misconception. Another child might respond that there would be no shadow when the light is turned on, because the light is not going that way (pointing to the doll). This answer would be scored as accurate and as referring adequately to the direction of the light and the relationship between the light and the object in making the shadow.

Teachers' self-evaluations of implementation were summarized from written reports made following the completion of the unit. Teachers were asked to make a final evaluation of their success in teaching their own version of the light and shadows unit and of what they had learned as a result of participating in the institute program.

Teachers' opinions were also sought 1 year later in a structured interview. Trained interviewers (two graduate students in education) met individually with teachers in June to ask about their use of the unit on light and shadows and of conceptual change principles generally during the previous year (year 2). Also, teachers were asked to give a retrospective evaluation of their training program and to summarize their plans for using conceptual change teaching during the upcoming year (year 3).

Results

In this section, we present the results of the configurations checklist ratings of eight teachers' lessons and briefly discuss three individual cases. Next, we report results of the interviews conducted with the children by trained interviewers before and after each unit was taught. Finally, we summarize teachers' own evaluations of the unit and the summer institute.

Configurations Checklist Ratings

Ratings from the configurations checklist are summarized in Table 2 for the eight teachers who implemented the unit. Average ratings over the 31 features of lessons rated after training ranged from 1.8–2.8, indicating moderate to high implementation. The mean rating for all rated lessons after training was 2.4 on the three-point rating scale.

For the six teachers who had submitted tapes of their science teaching prior to the institute, comparisons were made between ratings of lessons taught before and after training. (Two teachers joined late and did not submit tapes of prior teaching.)

Each of the six teachers made substantial progress in implementing conceptual change teaching, as measured by the mean ratings for all 31 features combined. Despite the small sample size, differences between mean ratings before and after training proved to be statistically significant for the group, as indicated by the Wilcoxon signed-ranks test ($z = -2.20$; $p = .028$).

Increased implementation occurred in every category of lesson features. Based on the mean ratings of features within each category, these differences between ratings before and after training were all significant ($p < .05$), as indicated by the Wilcoxon signed-ranks test.

A more detailed picture of the ratings is given in Table 3, which reports mean ratings of all six teachers on each of the 31 features both before and after the summer institute. Although, on average, teachers showed at least partial implementation of all the rated features, they appeared to be more successful with some features than with others. Teachers were more successful with lesson segments such as "review," "development," and "investigations" than they were with "summary." Likewise, teachers implemented content features such

TABLE 2. Mean Ratings for Each Teacher on All 31 Features of Conceptual Change Teaching before and after Training

Teacher	Grade	Before Training	After Training: Lesson 4	After Training: Lesson 9
Betsy	3	1.5	2.8	2.8
Nan	3	1.8	2.7	2.8
Carol	K	1.3	1.8	2.0
Denise	1	1.5	2.5	2.6
Gail	1	1.8	2.3	2.4
Helen	K	1.7	2.4	2.5
Six teachers		1.6	2.4	2.5
Ann	1	N.A.	2.4	2.2
Barbara	1	N.A.	1.8	2.2
Eight teachers			2.3	2.4

NOTE.—1 = no implementation; 3 = high implementation; N.A. = not available.

TABLE 3. Mean Ratings on Each Category of Configurations Checklist for Six Teachers Combined, before and after Training

Category	Before Training	After Training: Lesson 4	After Training: Lesson 9
Lesson segments:			
1. Introduction	1.5	1.5	2.2
2. Review	1.3	2.7	2.7
3. Development (focus)	1.0	2.0	2.8
4. Development (elicit)	1.8	2.8	2.5
5. Investigations	2.2	2.5	2.8
6. Representation	1.2	3.0	1.8
7. Discussion	1.3	2.3	2.2
8. Summary	1.5	1.7	1.7
Content:			
1. Conceptual emphasis	1.0	2.2	2.3
2. Accuracy	2.5	3.0	2.8
3. Scientific emphasis	1.3	2.7	2.7
4. Appropriate representations	1.2	1.3	2.3
5. Ties concept across lesson(s)	1.2	2.2	3.0
Teacher role:			
1. Elicits students' conceptions	1.7	3.0	2.8
2. Provides discrepant events	1.5	3.0	2.2
3. Facilitates students' constructions of new concepts	1.7	2.2	2.5
Student role:			
1. Predict, explain	1.5	2.8	2.8
2. Test predictions	2.0	2.5	2.5
3. Represent results	1.2	2.8	2.5
4. Describe, discuss results	1.5	2.3	2.0
5. Apply everyday experience	1.0	1.2	1.3
6. Cooperate in small groups	1.8	2.3	2.5
Activities/materials:			
1. Permit salient effects	2.0	2.5	3.0
2. Related to lesson concept	2.0	2.5	3.0
3. Include discrepant event	1.2	2.2	2.5
Management:			
1. Workspace, materials ready	2.2	2.8	2.8
2. Rules, routines discussed	2.3	2.8	2.7
3. Rules, routines in place	1.8	2.5	2.7
4. Monitoring, consequences	2.0	2.7	2.7
5. Students take responsibility	1.8	1.8	2.2
6. Students on task	1.8	2.2	2.8

NOTE.—1 = no implementation; 3 = high implementation.

as "accuracy" and "scientific emphasis" better than "conceptual emphasis" and "developmental appropriateness of examples."

With respect to teachers' roles, teachers were better at eliciting and identifying students' misconceptions and in presenting discrepant events than in helping students to construct new knowledge. With respect to students' roles, particularly high implementation was observed in getting students to make predictions, but low implementation was noted on applications to everyday experience. Teachers had good success, as measured by these ratings, in providing appropriate activities and materials and in managing their classrooms.

Although group averages are useful in judging the general effects of training, they conceal important differences among individual teachers. Therefore, three individual cases are presented briefly to illustrate the variety and complexity of training effects.

Betsy—Dramatic Success

Betsy's (grade 3) ratings showed a dramatic change in lessons taught before and after intervention. In both lessons 4 and 9 of her light and shadows unit, she received the highest possible rating on 27 of 31 features. By contrast, before training, her lesson received only one such rating.

Betsy was one of those who came to the program quite dissatisfied with her past practices in science. Before training, her science lesson revealed serious management problems, especially in small-group activities, and her subject-matter knowledge of light and shadows was weak. She eagerly embraced the conceptual change orientation and used opportunities in the program to construct the various kinds of knowledge needed to implement the light and shadows unit. In particular, by the end of the academic year, she was one of the most knowledgeable in physics. At the conclusion of her unit, she wrote, "I would tell any teacher who comes to me for advice about this unit that if I can do it, so can she, but she will have to be really interested and willing to work hard. I will tell her that she can get ready for a unique opportunity to see kids working and learning in small groups. She'll be amazed at what kids can do in the right setting and that teaching for conceptual change does work."

Nan—Substantial Implementation

Nan was another third-grade teacher who was successful in implementing the light and shadows unit. In contrast to Betsy, Nan was relatively confident about science and had a good background in the physics related to the content of the unit. In interviews prior to training, Nan expressed a strong content-mastery orientation toward science teaching and an emphasis on children's understanding of science content. Ratings of her pretraining science lesson showed strong classroom-management features during whole-group instruction and intermediate implementation on many other features.

After the summer institute, Nan's lessons showed high implementation of almost all the rated features. Her confidence in her subject-matter knowledge enabled Nan to generate demonstrations and examples to address unexpected events and issues in lessons. For example, she encouraged children to discuss whether a hand held flat on a surface could have a shadow.

In her report after teaching the light and shadows unit, Nan commented, "In general, I felt fantastic about the unit, the kids' work in it, what they learned, and what I learned. . . . There was so much going on, so much to be pleased with, and so much to notice because it was all new. I felt like the kids were really learning some science concepts and without the encumbrance of a text and the reading and vocabulary problems that accompany it."

Despite the success Nan experienced, conceptual change teaching proved to be a difficult transition that was far from complete. As reported in an intensive case study (Smith, 1989), Nan experienced difficulty in giving up previously successful and well-practiced teaching and management routines that were more compatible with content-mastery approaches than with conceptual change strategies.

Carol—Limited Progress

Carol, a kindergarten teacher, was one of those who, despite interest, dedication, and hard work, had difficulty implementing the light and shadows unit. Although her lessons after the institute received higher ratings than her pretraining lesson, she implemented no more than seven of the 31 features at high levels.

At the beginning of the program, Carol's science teaching emphasized "hands-on" activities in which children made individual discoveries. Her science background was weak, especially in physical science. (When Carol found out that physics was involved in the unit, she nearly dropped out of the program.) As indicated in her presummer science lesson, management of science activities was a weakness.

Although Carol increased her knowledge in each of the areas of training, she was handicapped in implementing the light and shadows unit by student misbehavior. Carol was unsuccessful at implementing the necessary classroom rules and routines; consequently, other features of conceptual change were difficult or impossible to implement. As Carol herself put it, "I thought (to myself) that I was a pretty good teacher as far as my management went—until you opened my eyes. Now I see my flaws, and since last summer, have tried to be more conscious of the skills necessary to develop a good unit. . . . My problem with discipline was because I'm just too easy."

In summary, the configurations checklist ratings indicated substantial success among the eight teachers in implementing conceptual change teaching, although progress was varied and idiosyncratic. Teachers started with varied levels of knowledge and progressed in different ways.

Interviews with Children

Results of interviews with children before and after teachers had implemented the unit were available for six of the eight teachers discussed above. (One teacher borrowed her posttest results from us and misplaced them; interviewers failed to obtain pretest results on another teacher's class.) For each grade level, significant gains in mean scores from pre- to posttest were observed (see Table 4). For the first- and third-grade classes, who had the same interview, a grade × ability × gender analysis of covariance with the pretest as a covariate showed significant differences ($p < .05$) for ability group and gender, but no significant grade effect and no significant interactions. Adjusted mean scores were greater for boys than for girls and for higher-ability groups than for the low-ability groups. Thus teachers at each grade level appeared to be successful in bringing about conceptual change in students, as well as in implementing features of conceptual change teaching strategies. We are currently conducting a more detailed study of the changes in children's thinking.

Teachers' Evaluations of Units

A compelling supplement to the checklist ratings and interviews with students are teachers' comments written at the conclusion of their units. They record the ups and downs of teaching plus the strains of trying something new and different. Teachers were asked in making their reports to evaluate the success of their unit on light and shadows, to comment on the factors that led to successes and failures, to judge the effects of the unit on students' thinking, and to evaluate the extent to which they had been able to incorporate in their unit the features of conceptual change teaching as presented during the summer institute.

As noted earlier, two of the original 10 teachers failed to implement the unit. One of these, Fran (grade 1), dropped from the program after the conclusion of the summer institute. She had been asked by her district to participate in a second summer workshop and reported that her inability to continue was due to other heavy commitments in the

TABLE 4. Mean Total Scores and Standard Deviations for Children's Interviews before and after Unit on Light and Shadows

		Pretest		Posttest		
Grade	N	M	SD	M	SD	p Value
Third	34	30.4	6.1	41.1	7.0	.0001[a]
First	38	26.4	6.3	35.6	6.5	.0001[a]
Kindergarten	12	16.0	3.2	23.3	2.7	.0001[b]

[a] t test.
[b] Wilcoxon Matched-Pairs Signed-Ranks Test.

fall. The other, Pat (grade 1), was having difficult management problems with her class during the year and decided, with the concurrence of the institute instructor, not to risk implementation.

The eight teachers who implemented the unit all judged it to be a success. Comments ranged from Nan's "I felt fantastic about the unit" to Carol's "Much was accomplished by myself and the children." Without exception, they reported specific evidence that convinced them that children's thinking had changed. Denise's (grade 1) comments were typical. "I can definitely see that many of the kids made progress in understanding light and shadows. I have observed this during group lessons and activity time. I've observed kids helping one another, explaining and predicting. The kids have documented their knowledge on Magic Slate disk. They have also written stories and drawn pictures of what they learned in the various lessons. It was satisfying to see kids like Rob, Ada, Amy, and Sam become dissatisfied with misconceptions about light and shadows after discussing and working on activities."

Some teachers had conducted discussions about light and shadows with their students at the beginning and end of the unit. These discussions were frequently mentioned as convincing evidence of student progress. However, teachers appeared to be even more convinced by children's responses to daily activities and by their daily creations. Some, like Barbara (grade 1), were eloquent about children's responses. "But the results—ah, what results! Kids who don't talk, talking; kids who don't do, doing; kids who are loners, joining. All done by them! I didn't say talk, do, join—they did. I didn't say learn, understand, discover—they did! It felt like opening a door in invitation and having guests rush in! It felt the way that the books in college always said that teaching would feel—warm, rewarding, active. It felt alive!"

Others, like Helen (kindergarten) emphasized daily assignments. "The children were given an assignment at the end of each lesson—draw, color, cut, paste, relate what happened in class today. We used this as an evaluation tool and a bit of evidence. It is really wonderful! The [children's] books were impressive and showed a great deal of understanding. One of the most interesting conclusions—shadows don't have color of their own—was beautifully illustrated by a child who colored the object (an orange) and repeated the same object shadow—in black! Looking through the books would be enough to show the growth."

Teachers were sure that they could convince others of students' growth in understanding. Carol (kindergarten), for example, wrote, "My children made progress—very definitely. I can prove it because I kept notes on each kid; their art work over the 2-week period and their class participation are the major ways. I could show others this so they'd know, or show the tapes."

All eight teachers believed that they had been able to employ the conceptual change teaching strategies that had been presented. They made special mention of the strategies for eliciting and challenging misconceptions, for asking students to represent their thinking, for selecting activities and materials, and especially for managing the classroom. However, every teacher reported difficult days or specific problems in using the strategies.

The most common problem mentioned was time—never enough. Teachers had trouble estimating the time needed for lessons, so they were often caught short. Another common problem was management, especially the distraction of individual children who had trouble cooperating in small groups.

A final problem was that the new strategies seemed strange, awkward, or difficult to coordinate. Teachers would forget to use a strategy or inadvertently fall into old ways. Looking back, Carol recognized that "I did often forget to ask 'Why?' and have the children give their reason. This was lacking on my part, but I got better toward the end—it is something for me to continuously strive for and include in the future." Betsy commented on the difficulty of coordination:

> Some of the factors that seemed to make some lessons more successful than others were when a sense of timing developed and I knew how it felt to have things fall in place. Once that sense was intact, each day was a constant honing and refining process. Being able to keep the lesson moving was, for me, an integral part of success. It was difficult at first not to be distracted by all of the different facets of the subject matter that the students kept raising in the discussions. Keeping the "Big Idea" for the day in mind and making the activity simple but appropriate with excellent management were some of the keys to better lessons.

One strong impression that comes from reading teachers' comments is that implementing new practices such as conceptual change teaching strategies, when viewed from the perspective of the teacher, is a major undertaking. At the end of the first year, no teacher had mastered the new strategies completely despite spending considerable time and energy. Yet the progress made, even when moderate as viewed from the outside, was a dramatic transformation as viewed from the inside. Barbara (grade 1) is a case in point:

> Teaching science in this way was freeing! Away from the way I had been teaching science—I would show and tell, ask students questions about what I had been teaching (not to test for understanding, but to see who had bothered to pay attention), and pass out a ditto on the subject for the students to complete. This wasn't fulfilling—but it's the way I saw others doing it, and since I hadn't found a source of information on other ways, I fell into the rut. I didn't even know where to begin—but now I'll never go back.
>
> Did this unit feel good? In ways I can hardly explain! It felt good to see kids so alive. It felt good to push myself, to see what I could do, what I could handle. Falling on my face, figuring out what had gone wrong, and re-doing the lesson successfully was terrific! This whole process of reevaluating my philosophy of teaching, my goals for myself within this profession is something that hardly anyone gets a chance to do. And that is what is happening to me—I've been exposed to ideas which contrast so harshly with what I've been doing, that I've had to rethink through a lot of the bull I've taken and given and done.

Final Interviews with Teachers

Although one of the main purposes of the study was to determine the extent to which teachers had successfully implemented the unit on light and shadows during phase 2 of their training, we also were interested in whether or not they would use the unit subsequently and whether they would use principles of conceptual change teaching in other aspects of their work. Although we were unable to observe their later teaching, we did conduct extensive interviews with the teachers 1 full year after the year of classroom implementation. In this final interview, trained interviewers asked teachers a variety of questions concerning the kinds of subject-matter knowledge and their beliefs about science and science teaching; these data will be reported elsewhere. Also, interviewers asked teachers about their use of conceptual change teaching during the academic year just past (year 2 of the project) and about their plans for using conceptual change teaching during the upcoming year (year 3 of the project). Two of the original 10 teachers were not available for interviews.

Out of the eight teachers participating in the final interviews, six indicated that they had taught the light and shadows unit during the previous year (year 2). All eight mentioned specific ways in which conceptual change teaching principles had influenced their teaching outside of the light and shadows unit, and all eight had definite plans to use the unit in the upcoming academic year (year 3). Five of the eight teachers mentioned clear plans for using conceptual change principles outside the unit itself. Although no teacher developed and taught another conceptual change unit in science (or in any other subject), each teacher mentioned significant effects. For example, Denise reported changing her whole management system based on what she had learned. Carol said she had learned to wait longer for student responses. Barbara replaced math workbooks with activities twice a week. Ann said she began to interrelate science, math, and language arts.

The six teachers who had implemented the unit a second time reported good success, although four of them thought things had gone better the first time. Betsy, for example, tried the unit early in the year and reported that her third-grade class had not yet mastered classroom rules and routines. She planned to schedule the unit later in the year next time around. Nan reported some slippage because, without coaching, there was a loss of "pressure to try to do everything exactly the way it should be done." Denise was less satisfied because a shortened time schedule in the afternoon cut off unit activities. Gail reported using only "bits and pieces" of the unit. Although "kids liked it," she did not see strong evidence of conceptual change.

Two teachers reported better success the second time around. Carol, for example, said the unit was "more successful" and that "the kids loved it." Barbara was extremely satisfied with her use of the unit in an entirely new teaching assignment.

The two teachers who reported not using the unit gave as their reason competing pressures of other projects at their schools. Ann's school had new programs in science, math, and reading. Pat had moved to a new school with "too much going on at grade level to get organized." It is interesting that both teachers planned to implement the unit in the following year.

Beyond the specific changes reported by teachers, a general theme emerged. All eight teachers said, in one way or another, that the greatest changes occurred in the new attention that they gave to students' thinking. Denise put it this way: "I learned how to listen more carefully to children, think about what they're saying, let them go on their predictions, to be patient, to plan my lessons according to what the class knows and not what I think should be taught, and not take for granted that they already know something." Betsy noticed in her math teaching that, "I used to just get up and do it; it never occurred to me to find out what they already knew. I *now* realize the amount of misconceptions that children come to school with, and it was something that I never thought about before. . . . It's amazing to me—the depth of children's thinking; it is not always "correct," but they just feel so strongly or think so strongly about their ideas, and maybe I just never gave it credibility."

Even Pat, who had yet to implement her unit, mentioned trying "to allow more time to get ideas from children" and "to ask more appropriate questions to find out what they are really thinking."

Asked about their plans for the coming year, all eight teachers said that they intended to teach the light and shadows unit. However, only Betsy, Nan, and Denise mentioned plans to extend such teaching to other science units. No one mentioned specific plans to develop conceptual change units in other subjects. The stage of teachers' developing expertise was best characterized by their responses to a question about whether they would be interested in teaching a new unit on heat and temperature, if it were available. Nan spoke for the most confident in saying, "Definitely. Where is it?" Ann spoke for the majority in saying, "I would try." Although they were comfortable with the light and shadows content, most teachers believed that they would need help with subject-matter knowledge and familiarity with specific activities and materials before taking on a new conceptual change unit.

Teachers' Evaluations of the Program

During the final interview, the eight teachers were asked to rate how comfortable they had become with various activities related to conceptual change teaching. All eight reported feeling much more comfortable with understanding children's thinking and with planning and teaching conceptual change lessons. With one or two exceptions, they all felt more comfortable in understanding the physics of light and shadows, choosing curriculum and materials, organizing and managing small groups, and conducting discussions.

When asked to rate components of the program in terms of helpfulness, the unanimous top rating was given to the planning sessions with the expert coach. In order of helpfulness, teachers rated other components as follows: readings about children's thinking, first week together in the summer, teaching small groups of children in summer camp, having coaching while teaching, watching videotapes of one's own teaching, readings about conceptual change teaching, writing in log or journal, writing curriculum in grade-level team, coaching others, and monthly seminars. All of the activities were considered to be at least "somewhat helpful," and all except the last three were given average ratings of "most helpful."

Finally, teachers were asked to rate activities that might be helpful to them in terms of their continuing growth in teaching science to young children. Teachers gave top priority to workshops with materials and activities on science. Next, in order of helpfulness, were readings about children's thinking, revisions in state or district curriculum, new units on other topics, ongoing discussion with other teachers, the principal's support and feedback, regular coaching, and developing curriculum oneself. All of the items were considered to be either helpful or very helpful.

Summary and Discussion

The major result of the study was to document that eight of 10 primary teachers who attended the summer institute were able to implement a conceptual change unit on light and shadows in their classrooms. Although implementation varied among participants and among features of the teaching strategies, the results indicate that teachers in the primary grades can use conceptual change strategies successfully. Granted, the teachers in this study had unusually strong support, including a demonstration unit and coaching; nevertheless, the results are highly encouraging compared to the dismal record of past efforts to improve elementary science teaching (e.g., Stake & Easley, 1978). Furthermore, based on interviews with the teachers 1 year later, apparently all eight of those interviewed, even without coaching, continued to use the strategies they had learned. As always, such reports must be interpreted with caution. There did seem to be some slippage for teachers during the second year. Yet because their practice is supported by changes in their underlying knowledge, we are optimistic about their chances for continuing to practice and learn from this new way of teaching.

In some cases the training seemed to be accompanied by less observable but no less dramatic shifts in teachers' orientations toward teaching science and other subjects. The most general shift was a new emphasis given to the role of students' conceptions. Almost all teachers mentioned new sensitivity and new willingness to listen to children's ideas as a central outcome of their experience. This shift is similar to the result described by Carpenter et al. (1988) with first-grade teachers who were taught about children's thinking in mathematics, even though the intervention strategies were different.

Despite the positive effects of the training, results also indicate that teachers had to make strenuous efforts to construct the knowledge required for this type of teaching. An interesting aspect of the research program has been the attempt to document teachers' views of the changes. Subject-matter knowledge, including knowledge about students' misconceptions and how to challenge them, did not come easily for most. Some teachers were still working hard on their understanding of the physics content at the end of the first year. Knowledge about how to involve children in inquiry and about how to get young children to represent their new knowledge was likewise difficult to develop. If teachers in the project are typical, a feeling of inadequacy in these aspects of science may be one reason why teachers rely on fact-oriented, textbook instruction or offer loosely structured, "hands on" science activities that often contribute little to children's conceptual development.

As illustrated in the present project, teachers need not only a vision of something better but also various kinds of knowledge that they can use to bring the vision to life. As suggested by the cognitive-apprenticeship model, just like the knowledge of any novice craftsman or professional, such knowledge appears to be acquired by degrees and gradually coordinated for flexible use. Propositional knowledge about students' ideas and about teaching strategies will be insufficient for change in teachers' practice unless it is augmented by procedural knowledge of how to plan for and implement teaching strategies within an effective lesson structure. Also needed is the conditional knowledge about when to use such strategies appropriately (Berliner, 1989; Brophy, 1988).

To acquire the propositional, procedural, and conditional knowledge, teachers need scaffolding for support. Among the supports teachers in this project valued were those that gave them specific information about children's thinking, as well as materials and activities they could use in teaching. Also valued were discussions with other teachers and especially interaction with an expert coach while developing teaching plans. In addition, teachers appreciated opportunities to teach small groups and to receive feedback on their videotaped teaching. These evaluations are consistent with the assumptions of cognitive-apprenticeship training, in which novices are given help and guidance by an expert as they undertake a series of tasks that are graded in difficulty. In this case, implementing a unit on light and shadows after training with a demonstration unit appeared to be a significant, though difficult, step toward expertise in conceptual change teaching for these primary teachers.

Focusing on a single topic, light and shadows, was a significant strength and also a limitation of the program. By limiting the scope of subject-matter knowledge, primary teachers could construct the subject-matter knowledge needed for successful implementation, even while they were acquiring knowledge of teaching and management strategies. With the possible exception of Nan, who had good subject-matter knowledge to begin with, the strategy appeared to be an essential part of the scaffolding provided. Other teachers were perilously low on subject-matter knowledge, and they knew it. Giving them a realistic, positive opportunity to acquire such knowledge in connection with a teaching unit appeared to be a highly successful feature of the training.

The limitation of the strategy is, of course, that the changes in science teaching occur primarily, perhaps only, within the single unit. Based on our experience, changes were primarily within the unit on light and shadows, although teachers did report influences on their beliefs and teaching practices generally. We believe that such limitations are not a flaw in the training strategy as much as a recognition of how difficult it is for primary teachers to revolutionize their science teaching and to improve their subject-matter understanding significantly.

Even the present project, with a limited focus on a single unit, with a demonstration model and coaching, with careful scaffolding tailored to individual needs—even such training did not produce teachers who were experts. Although many of the teachers with whom we worked were recommended as highly competent in traditional areas of their teaching, most were relative novices in teaching for conceptual change in science lessons. In terms of Berliner's (1989) discussion of stages of expertise, these teachers appear to have acquired new patterns of thinking and teaching, but these patterns have not yet become fluid and coordinated. Instead, teachers appear to have taken a dramatic, yet strictly limited, step toward expertise in conceptual change teaching. Before conceptual change strategies are fully implemented throughout their science program, these primary teachers would need to have much additional support of a similar kind.

Is it realistic to think that the kinds of support given to teachers in this program can be made available to teachers generally? Perhaps not in the intensive format described here. We are developing variations on the program and working with small groups of teachers in our area. Conceptual change units in earth science and weight and balance are the basis for both summer courses and in-service programs during the year. In the latter case, teachers bring their students to the curriculum laboratory classroom where both the demonstration teacher and the regular class teacher share the planning and teaching. In this setting, the scaffolding is somewhat different from the summer institute program, but the modeling and coaching process is basically the same. We believe that existing resources now devoted to in-service teacher education could be redirected along these lines to have a significant effect on many more teachers. As some teachers become more knowledgeable and expert in their science teaching, for example, they might become demonstration teachers and coaches for others.

As far as the provision of continuing supports for such teaching in schools goes, we are less sanguine. If science is taught 2 days per week between 2:00 and 2:30 P.M., if principals and parents care mainly about reading and math achievement, and if appropriate equipment and supplies are not available, even teachers who are enthusiastic about this type of teaching will experience "slippage." Furthermore, if teachers are not given the opportunity, time, and support to construct the substantive and pedagogical-content knowledge underlying the curriculum they are asked to teach, then no doubt we will continue to see short-cut teaching strategies that emphasize superficial "coverage" of science textbook topics or loosely structured, hands-on activities that often add little to students' understanding of science. We must recognize that such problems do not represent defects in our training strategies; rather, they are failures to use and support the strategies we have.

What implications do we see for preservice teacher education programs? This is a more difficult question. Surely, the exploration of such a question would require more information than we have on the knowledge and beliefs that preservice teachers bring to their teacher training. Like Shulman (1986), we see the need to emphasize the development of content knowledge, especially pedagogical content knowledge. With elementary teachers, such an emphasis presents difficult problems because of the wide range of content they could be asked to teach in science as well as in other subjects. Furthermore, college science courses commonly include teaching strategies and forms of representations that are far removed from those likely to be effective in primary classrooms. Special courses that teach substantive knowledge in conjunction with both pedagogical-content knowledge and pedagogical knowledge appear to be desirable. Based on our experience, such courses need to have practical components so that students may construct the subject-matter knowledge in relation to lesson structure and so that the knowledge has some flexibility in use. However, we would expect, along with Berliner (1989), that preservice teachers would have even more difficulty than did our experienced teachers in coordinating the various forms of knowledge. As novices, they lack the fund of episodic memories, practical knowledge, and frameworks for structuring and interpreting classroom events that characterize the thinking of expert teachers. Therefore, objectives for preservice teacher education would need to be modest, and the scaffolding would need to be plentiful. Training would emphasize *learning to learn* about science teaching and would rely on the intensive study of a small number of topics rather than on broad coverage of many topics. For this purpose, case knowledge, such as that contained in the demonstration unit used in this study, should prove extremely useful.

Now that we have documented changes in teachers' knowledge and teaching practice, we plan to examine our data in detailed case studies of the teachers involved to see more specifically how knowledge changes were related to the classroom science teaching we observed (e.g., Smith, 1989). As Tobin and Fraser (1987, p. 213) put it, "The challenge that faces researchers in the wake of the Exemplary Practice in Science and Mathematics Education Study is to identify how teachers can construct knowledge about content and teaching so that their teaching performance improves. . . . We must learn more about the role of different knowledge forms in teaching."

How does teachers' knowledge guide their planning and affect what they notice in classroom lessons? What role does it play in their decision making while teaching? To what extent does one kind of knowledge (e.g., pedagogical knowledge of lesson structures) influence teachers' ability to use other kinds of knowledge (e.g., knowledge of teaching strategies)? These and other related questions remain to be investigated in more detail as we continue our attempts to understand the role of teachers' knowledge in primary-grade science teaching.

Appendix

Features of Conceptual Change Teaching Rated on Configurations Checklist

Lesson Segments	
1. Introduction	Teacher comments on lesson's topic and activities with reference to conceptual content.
2. Review (if not first lesson)	Teacher asks students for description of previous lessons' conceptual content and probes their understanding.
3. Lesson focus	Teacher clearly presents a single focus to a concept or problem.
4. Lesson development	Teacher elicits students' ideas about concept, gets predictions and explanations, and probes understanding.
5. Investigations/activities	Students manipulate materials to test new ideas. Teacher probes, questions, checks students' understanding.
6. Representation	Students represent results of activities in a way that allows teacher's probe of understanding (e.g., writing, graphs, drawings) in the whole-class discussion.
7. Discussion	Students share results and discuss evidence while teacher encourages discussion of evidence. Focus is on student thinking.
8. Summary	Teacher encourages students to summarize findings and connect them to the conceptual content of previous and future lessons.

Content Features

1. Teacher emphasizes students' conceptual understanding and conceptual change in previous ideas.
2. Teacher's own presentation is conceptually accurate.
3. Lesson focuses on an important scientific model or explanation.
4. Teacher uses examples, analogies, and metaphors that are conceptually and developmentally appropriate.
5. Teacher ties conceptual content across lesson segments and/or across lessons.

Teacher Role

1. Teacher elicits and diagnoses students' conceptions of content under study and asks them to predict and explain events.
2. Teacher contradicts students' thinking by providing discrepant events, encouraging debate, and/or challenging students' ideas.
3. Teacher facilitates students' construction of science conceptions by contrasting ideas, encouraging discussion, asking for applications, and/or modeling cognitive processes.

Student Role

1. Students verbalize ideas by predicting, explaining, and discussing ideas relating to concept under study.
2. Students work with materials to investigate ideas and test predictions.
3. Students represent (e.g., writing, drawing, graphing) results of investigations for later sharing and discussion with teacher and other students.
4. Students describe, demonstrate, and discuss results with teacher and other students in relation to own ideas.
5. Students apply concepts to everyday events and explain how concepts are related to everyday events.
6. Students work and discuss ideas in small cooperative groups or pairs, as well as in whole-group meetings.

Activities and Materials

1. Materials and activities are familiar and allow students to produce immediate, observable, salient, and varied effects.
2. Activities are clearly tied to concept in lesson.
3. Activities include discrepant events that clearly contradict students' thinking.

Management Features

1. Teacher has arranged classroom so that work space is available, materials are ready and accessible, traffic flows smoothly.
2. Teacher has established positive expectations for cooperative work, involves students in discussions of needed rules and routines, and of reasons why these are important for their work (or this appears to have been done previously).
3. Teacher teaches, explains, or provides feedback on needed rules and routines (or they seem to be in place).
4. Teacher consistently monitors students' behavior, acknowledges appropriate behavior, and applies agreed-on consequences.
5. Students take responsibility for maintaining cooperative work environment.
6. Students generally follow rules and routines, monitor their own behavior, remind friends of rules and routines, are generally on task.

Note

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