Classroom Lessons: Integrating Cognitive Theory and Classroom Practice

edited by Kate McGilly

A Bradford Book
The MIT Press
Cambridge, Massachusetts
London, England

progress of the knowledge-building discourse or perhaps helping it to move ahead to a fuller understanding of adaptation.

Standard-brand cognitive science is helpful in working at the World 2 level, but it is essentially mute with respect to World 3. This makes cognitively oriented educators susceptible to a very serious confusion between (a) the way knowledge is organized in the mind of the child (World 2) and (b) the child's knowledge of the way knowledge is organized in a domain (World 3). It also prevents educators from considering misconceptions, simplified models, and the like as objective entities that can be evaluated, discussed (with the students), and investigated as to their effects on the course of knowledge building. We find that a cognitive science that makes a more radical break with folk psychology and commonsense epistemology offers a better basis for progress in educational design (Bereiter 1992).

Notes

The research reported in this chapter was supported by the James S. McDonnell Foundation. Development of the CSILE system has been supported by Apple Computer, Inc., External Research Division; IBM Corporation; the Ontario Ministry of Colleges and Universities; and the Ontario Ministry of Education. The authors wish to acknowledge the contributions of Clare Brett, Jud Burtis, and Nancy Smith Lea to the evaluation research and to preparing evaluation data for this chapter. We owe special thanks to the students we have worked with and their teachers: Kathy Frecker, Rosemary Kelly, Chuck Laver, and Jim Webb.

1. To name a few, besides ourselves, who have demonstrated this shift in emphasis, there are Ann Brown, John Bransford, Joe Campione, Jerry Duffy, Annemarie Palincsar, and Alan Schoenfeld.
2. Mechanical problems with the computers severely limited use of CSILE in the grade 4/5 classroom this year and so we report results for the grade 5/6 classes only.

Chapter 9

Guided Discovery in a Community of Learners

Ann L. Brown and Joseph C. Campione

The educational community in America is again facing a time of reform. Dissatisfied with the status quo, many are asking for widespread changes in public education. This is not new. Indeed, some have argued that education during the twentieth century has consisted of cycles of reform and retrenchment, with the actual business of schooling remaining largely unchanged (Cohen 1988; Cuban 1984, 1990).

Our current program is similar in many ways to earlier reform endeavors, most notably progressive education, discovery learning, and other movements influenced by the work of John Dewey (Cremin 1961; Dewey 1902; Graham 1967). Via a series of gradual steps leading from the laboratory to the classroom (Brown 1992), we find ourselves involved in a project that resembles the famous six-year experiment mounted by Dewey in the Chicago laboratory school at the turn of the century (Dewey 1894, 1897, 1936; Mayhew and Edwards 1936). We have, in effect, adopted a grade school.

As a result, when describing our work, we run up against some pervasive myths surrounding Dewey's laboratory school. We are often asked how the work differs from Dewey's, and why we think we can succeed where Dewey failed. Few, however, seem to know much about what Dewey actually did, or by what criteria his experiment can be viewed as a failure. Although it is undoubtedly true that our classroom research shares philosophical underpinnings with Dewey's approach, there are some subtle and not-so-subtle differences (Brown 1992). We will illustrate this point by considering two articles of Dewey's faith (1902) as received wisdom would have it: discovery learning and the nature of the curriculum.

The best-known tenet of Dewey's pedagogical creed (1897) is the concept of "discovery learning." It is argued that children learn best when discovering for themselves the "verities of life." This notion has been fully incorporated into constructivist theories of learning. Discovery learning, when successful, has much to recommend it. The motivational benefits of generating and testing one's own knowledge cannot be underestimated.

Discovery learning is often contrasted with didactic instruction. Both methods have their critics. On the one hand, there is considerable evidence that didactic teaching leads to passive learning. But, on the other hand, unguided discovery can be dangerous: children "discovering" in our classrooms are quite adept at inventing biological misconceptions (Brown 1992; Brown and Campione 1990; Brown and Palincsar 1989a). And, the exact role of the teacher in discovery learning classrooms is still largely uncharted.

We have argued in favor of a middle ground between didactic teaching and untrammeled discovery learning, that of "guided discovery" (Brown 1992; Brown and Palincsar 1989b), where the teacher acts as a facilitator, guiding the learning adventures of his or her charges. Guided discovery, however, is difficult to orchestrate. It takes sensitive clinical judgment to know when to intervene and when to leave well enough alone. To be successful, the guide must continually engage in on-line diagnosis of student understanding, and must be sensitive to the current "zone of proximal development" (Vygotsky 1978), the "region of sensitivity to instruction" (Wood and Middleton 1975), the "readiness arena," or "bandwidth of competence" (Brown 1979; Brown and Reeve 1987), where students are ripe for new learning. Guided discovery places a great deal of responsibility in the hands of the teacher, who must model, foster, and guide the "discovery" process into forms of disciplined inquiry that may not be reached without this expert guidance.

Dewey was also concerned about the curriculum of public education, again an enduring topic of debate (Kliebard 1987). What knowledge of enduring value should the child be guided to discover? And should this decision be colored by considerations of age, ability, ethnicity, etc? Most would agree with Bruner (1969) that knowledge in the form of "lithe and beautiful and immensely generative" ideas should form the basis of any curriculum. Immensely generative ideas may be few, and the idea behind education is to point students in the right direction so that they may discover and rediscover these ideas continuously, deepening their understanding in a cyclical fashion (Bruner 1969). It is surely unreasonable to expect students to reinvent such generative ideas for themselves, and it is the teacher who is called upon to orchestrate this discovery process. In this chapter we will focus primarily on ways of assisting discovery learning within rich content areas. We will also describe our attempts to relieve the demands on the official guide, the teacher, by introducing expertise into the system through drawing on a wider community of learners.

Brief History of the Project

The project that we currently refer to as the "Community of Learners" program, for want of a better name, has its historical roots not in the pedagogy of philosophers such as Dewey, nor in the cyclical reform movements of educational politics (Cuban 1990; Dow 1991), but in the changes that have occurred in psychological learning theory over the last thirty years. Under the auspices of the so-called cognitive revolution, major changes in psychological learning theory took place, changes that had important implications for educational practice.

The cognitive transformation of psychological learning theory led to renewed emphasis on several key ideas. First, although the concept of autodidactic learning (Bateson 1963; Binet 1909; Whitehead 1916) has a long history, it was not until recently that learners have become widely viewed as active constructors of knowledge, rather than passive recipients of others' expertise. Second, the contemporary ideal learner is imbued with powers of introspection, once verboten. We now recognize that one of the most interesting things about human learning is that the learner has knowledge and feelings about it (Tulving and Madigan 1970), sometimes even control of it—metacognition if you will (Brown 1975; Flavell and Wellman 1977). Third, we now recognize that humans, although excellent all-purpose learning machines, equipped to learn just about anything by brute force like all biologically evolved creatures, come predisposed to learn certain things more readily than others (Carey and Gelman 1991).

This concentration on active, strategic learning (Brown 1974), with the learner's understanding and control (Brown 1975, 1978), following domain-specific trajectories (Brown 1982, 1990; Carey and Gelman 1991; Gallistel, Brown, Carey, Gelman and Keil 1991) had a major influence on our research program in particular and on the gradual shift toward studying learning in educational settings in general.

Concomitant with the growing emphasis on active, self-conscious, self-directed learning were far-reaching modifications in what students were required to learn, together with the contexts in which they were asked to learn it. During the 1970s, psychologists began studying the acquisition of expertise within specific domains, gained over long periods of time via concentrated, and often self-motivated, learning (chess for example). More recently, learning theorists became concerned with the acquisition of disciplined bodies of knowledge, characteristic of academic subject areas (e.g., mathematics, science, computer programming, and even social studies). Learning theories had to change to reflect this shift in emphasis (Glaser and Bassok 1989). Furthermore, psychologists began to broaden their scope and consider input from other branches of cognitive science as well as from learning settings outside the laboratory, or even the classroom walls (Heath and McLaughlin, in press; Lave and Wenger 1991).

Reciprocal Teaching

Our original move outside the safe haven of the laboratory into classroom learning began with an extended series of studies of reading comprehension. We introduced a procedure, "reciprocal teaching," that was designed to improve reading in underachieving students (Brown and Palincsar 1982, 1989b; Palincsar and Brown 1984). In a typical reciprocal teaching session each participant in a reading group of approximately six members takes a turn leading a discussion. This "learning leader" begins by asking a question about the core content and ends by summarizing the gist of what has been read. Questioning provokes discussion, and summarizing helps students establish where they are in preparation for tackling a new segment of text. On chosen occasions the leader asks for predictions about future content and attempts to clarify any comprehension problems that might arise. These key activities of questioning, summarizing, clarifying, and predicting provide the repeatable structure necessary to get a discussion going, a structure that can be faded out when students are more experienced in leading and taking part in discussions.

Approximately a decade of research has seen significant changes in reciprocal teaching, as illustrated in table 9.1. We began working one-on-one with children who were reading unconnected passages in laboratory settings (Brown and Palincsar 1982), progressed to studying children "pulled out" in order to work in groups in resource rooms (Palincsar and Brown 1984), then to considering naturally occurring reading groups in the classroom (Brown and Palincsar 1989b), and finally to studying reading comprehension groups that were fully integrated into science classrooms (Brown and Campione 1990; Brown and Palincsar 1989a; Brown, Ash, Rutherford, Nakagawa, Gordon and Campione, in press). We began by concentrating on the few constrained strategies described above but quickly upped the ante by demanding that students describe the gist of entire texts and put their new knowledge to use via analogical extension and problem solving (Brown, Campione, Reeve, Ferrara, and Palincsar 1991). Next, we began modeling and supporting the development of complex explanation, argument, and discussion forms (Brown 1991). Most recently, we have fostered the development of complex reasoning and thought experiments as a method of building new knowledge (Brown et al., in press). Initially we looked at students reading unconnected passages, then proceeded to look at students reading coherent content (Brown

Table 9.1
Evolution of reciprocal teaching (RT)

Context	One-on-one in laboratory settings	Groups in resource rooms	Naturally occurring groups in classrooms	Work groups fully integrated into science classrooms
Activities	Summarizing, questioniong, clarifying, predicting	Gist and analogy	Complex argument structure	Thought experiments
Materials	Unconnected passages	Coherent content	Research-related resources	Student-prepared material
Pattern of use	Individual strategy training	Group discussion	Planned RT for learning content and jigsaw teaching	Opportunistic use of RT
Initiation of activity	Researcher-initiated	Researcher- and teacher-initiated	Teacher initiated with researcher guidance	Initiated by students

et al., 1991; Brown and Palincsar 1989a; Palincsar, Brown, and Campione, 1990). We are now observing reading comprehension as it takes place in social groups reading, discussing, and arguing about cohesive material they have prepared themselves. In our current classrooms students appropriate and adapt reciprocal teaching as a tool to enhance their comprehension. Faced with important material they have difficulty understanding, they call for a reciprocal teaching session to enhance and monitor their learning (Brown et al., in press).

Communities of Learners

In our current work, reciprocal teaching is only one component of a learning community designed to encourage distributed expertise (Brown 1992; Brown et al., in press). In order to foster such a community, we feature students as designers of their own learning; we encourage students to be partially responsible for designing their own curriculum. In addition to reciprocal teaching, we use a greatly modified version of the jigsaw method (Aronson 1978; Brown et al., in press) of cooperative learning. Students are assigned curriculum themes (e.g., changing populations), each divided into approximately five subtopics (e.g., extinct, endangered, artificial, assisted, and urbanized populations). Students form separate research groups, each assigned responsibility for one of the five or so subtopics. These research groups prepare teaching materials using commercially available, stable computer technology (Campione, Brown and Jay 1992). Then, the students regroup into reciprocal teaching seminars in which each student is expert in one subtopic, holding one-fifth of the information. Each fifth needs to be combined with the remaining fifths to make a whole unit, hence "jigsaw." All children in a learning group are expert on one part of the material, teach it to others, and prepare questions for the test that all will take on the complete unit. It is important to note that all children are finally responsible for mastery of the entire theme, not just their fifth of the material. So the burden of teaching others from expertise is a real one, and a mainstay of these classrooms.

The Ideal Classroom

Working with a group of teachers, and with students at different grade levels[1], we have evolved a view of the essential features that characterize our ideal classroom environment. Because all new teachers are involved from the outset in the organic growth of their versions of the program, versions compatible with our underlying learning principles and their own practices, there is considerable variability in different classes. But there is also constancy at the level of underlying principles. Together with the teachers we have settled on several characteristics of successful classrooms that must be operating for the program to be judged in place. These essential characteristics are

Individual Responsibility Coupled with Communal Sharing. Students and teachers each have "ownership" of certain forms of expertise, but no one has it all. Responsible members of the community share the expertise they have or take responsibility for finding out about needed knowledge. Through a variety of interactive formats, the groups uncover and delineate aspects of knowledge "possessed" by no one individual. Expertise is distributed deliberately through the jigsaw and reciprocal teaching collaborative learning activities that ensure students learn complementary material and can thus teach from strength.

Expertise is also distributed by happenstance; variability in expertise arises naturally within these classrooms (Brown et al., in press). We refer to this phenomenon as "majoring." Children are free to major in a variety of ways, free to learn and teach whatever they like within the confines of the selected topic. Children select topics of interest to be associated with: some become resident experts on DDT and pesticides; some specialize in disease and contagion; younger children often adopt a particular endangered species (pandas, otters, and whales being popular). Within the community of the classroom, these varieties of expertise are implicitly recognized, although not the subject of much talk.

Subcultures of expertise develop: varieties of expertise are recognized by the pattern of help seeking and the role students assume in small and whole class discussions. In these discussions, the class defers to expert children in both verbal and nonverbal ways. Status in discussions does not reside "in" the individual child, however, as in the case of established leaders and followers, but is a transient phenomenon that depends on a child's perceived expertise within the domain of discourse. As the domain of discourse changes, so, too, do the students receiving deferential treatment.

It is very much our intention to *increase diversity* in these classrooms. Traditional school practices have aimed at just the opposite, decreasing diversity, a traditional practice based on several assumptions: that there exist prototypical, normal students, that, at a certain age, they can do a certain amount of work or grasp a certain amount of material, and that they can do so in the same amount of time (Becker 1972). Now these are strong assumptions! They must serve a powerful administrative function (Cuban 1984), for there is little that we know about learning and development that would support them. So although we must aim at conformity on the basics, everyone must read eventually, we must also aim at increasing diversity of expertise and interests so that members of the community can benefit from the increasing richness of knowledge available. The essence of teamwork is pooling varieties of expertise. Teams composed of members with homogeneous ideas and skills are denied access to such diversity.

Ritual, Familiar Participant Structures. Principal participation frameworks (Goodwin 1987) are few and are practiced repeatedly. One common classroom routine is for the students to be divided into three groups, one composing on the computers, one conducting research via a variety of media, and the last (the remaining children) interacting with the teacher in some way: editing manuscripts, discussing progress, or receiving some other form of teacher attention. A second repetitive frame is for the class to engage in reciprocal teaching research seminars or jigsaw teaching activities, with approximately five research/teaching groups in simultaneous sessions. Another activity, "crosstalk," was introduced by the students. In crosstalk, students from the various research groups periodically report in about their progress to date, and students from other working groups ask questions of clarification or extension. The various groups thereby talk "across groups" and provide comprehension checks to each other. And the final activity features the classroom teacher, or an outside expert, conducting a benchmark lesson, modeling thinking skills and self-reflection, introducing new information, stressing higher-order relationships or encouraging the class to pool their expertise in a novel conceptualization of the topic. The repetitive, indeed, ritualistic nature of these activities is an essential aspect of the classroom, for it enables children to make the transition from one participant structure (Erickson and Shultz 1977) to another quickly and effortlessly. As soon as students recognize a participant structure, they understand the role expected of them. Thus, although there is room for individual agendas and discovery in these classrooms, they are highly structured to permit students and teachers to navigate between repetitive activities as effortlessly as possible.

A Community of Discourse. It is essential that a community of discourse (Fish 1980) be established early in which constructive discussion, questioning, and criticism are the mode rather than the exception. Speech activities involving increasingly scientific modes of thinking, such as conjecture, speculation, evidence, and proof become part of the common voice of the community; conjecture and proofs are themselves open to negotiation in multiple ways (Bloor 1991) as the elements that compose them, such as terms and definitions, are renegotiated continuously. Successful enculturation into the community leads participants to recognize the difference between, and the appropriate place of, everyday versions of speech activities having to do with the physical and natural world and the discipline-embedded special versions of these activities (O'Connor 1991).

Multiple Zones of Proximal Development. Theoretically, we conceive of the classroom as comprised of multiple zones of proximal development (Vygotsky 1978) through which participants can navigate via different routes and at different rates (Brown and Reeve 1987). A zone of proximal development can include people, adults and children with varying expertise, but it can also include artifacts such as books, videos, wall displays, scientific equipment, and a computer environment intended to support intentional learning (Scardamalia and Bereiter 1991). The zone of proximal development defines the distance between current levels of comprehension and levels that can be accomplished in collaboration with other people or powerful artifacts. It embodies a concept of readiness to learn that emphasizes upper, rather than lower, levels of competence, boundaries that are not immutable, but rather constantly changing as the learner becomes increasingly independent at successively more advanced levels.

Seeding, Migration, and Appropriation of Ideas. In our classroom, teachers and students create zones of proximal development by *seeding* the environment with ideas and concepts they value and by harvesting those which "take" in the community. Ideas seeded by community members *migrate* to other participants and persist over time. Participants in the classroom are free to *appropriate* vocabulary, ideas, methods, etc., that appear initially as part of the shared discourse, and by appropriation, transform these ideas via personal interpretation. Ideas that are part of the common discourse are not necessarily appropriated by all, or in the same manner by everyone. Because the appropriation of ideas and activities is multidirectional, we use the term *mutual appropriation* (Moschkovich 1989; Newman, Griffin and Cole 1989; Schoenfeld, Smith and Arcavi, in press).

Mutual appropriation refers to the bidirectional nature of the appropriation process, one that should not be viewed as limited to the process by which the child (novice) learns from the adult (expert) via a static process of imitation, internalizing observed behaviors in an untransformed manner. Rather, learners of all ages and levels of expertise and interests seed the environment with ideas and knowledge that are appropriated by different learners at different rates, according to their needs and to the current state of the zones of proximal development in which they are engaged.

The Nature of the Curriculum

The Intended Curriculum

Although there is considerable room for discovery and individual majoring in these classrooms, we intentionally engineer the curriculum in certain ways. The teacher's role here is complex. Teachers must see that curriculum content is "discovered," understood, and transmitted efficiently and at the same time she must recognize and encourage students' independent majoring attempts. But what is the place of a set curriculum in discovery classrooms? True, it would be possible to allow the students to discover on their own, charting their own course of studies, exploring at will, but, in order to be responsive to the course requirements of normal schools, we believe it necessary to set bounds on the curriculum to be covered. In general, our approach is to select enduring themes for discussion and to revisit them often, each time at an increasingly mature level of understanding. For example, in biology we concentrate on interdependence and adaptation.

Changes in the curriculum occur over time because individual participating teachers help to design the actual expression of the main units, and the students themselves are allowed some freedom to nominate subunits for study, subunits constrained by a given theme. For example, the classroom teacher and the resident biologist select a unit theme, such as endangered species. The class meets for whole class sessions where they discuss what they already know and what they

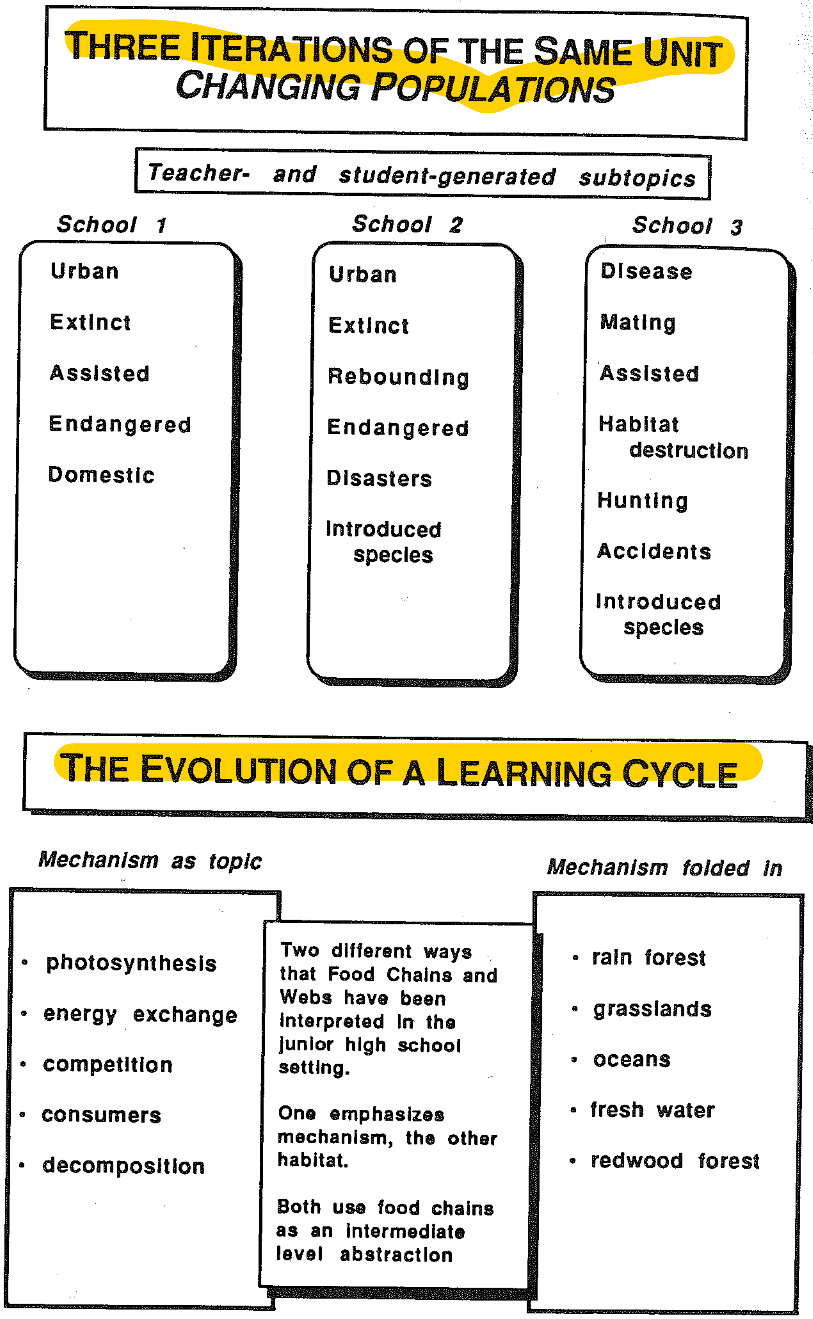

Figure 9.1
Changes in the curriculum of three sixth-grade classes (top) and two seventh-grade classes (bottom) as the result of teacher and student interests

want to find out. Questions thus generated are written on Post-its™, and placed on a bulletin board. Students then browse through a few highly selected books and generate more questions. Finally, the questions are grouped into subthemes and identified as the subunits. Thus, although there is a great deal of similarity across groups in the subunits, students feel ownership and volunteerism in what they select for study. The top half of figure 9.1 shows the variation in subthemes that three separate sixth grade classes helped generate under the unit, changing populations.

Similarly, teachers differed in how they orchestrated the study of units, partially in response to their own preferences and partially in response to student interest. The bottom half of figure 9.1 shows two different approaches to studying the food chain. In one case the focus was on mechanism; in the other on habitats and ecosystems. In the "Mechanism as Topic" class, students were led to consider different habitats as they concentrated on photosynthesis and energy exchange. Correspondingly, in the "Mechanism Folded In" class, those specializing in individual habitats were led to consider the basic mechanisms (photosynthesis, energy exchange, etc.) as they endeavored to understand their habitats (Ash and Brown 1993).

Under the general umbrella of the themes and subunits, students are introduced to some critical underlying notions. Grade school children become increasingly interested in cross-cutting themes that would form the basis of an understanding of such principles as metabolic rate, reproduction strategies, and hibernation as a survival strategy, although at a very elementary level. For example, a member of a group studying elephants became fixated on the amount of food consumed by his animal and subsequently by other animals studied in the classroom, notably the panda and the sea otter. Although relatively small, the sea otter consumes vast quantities of food because "it doesn't have blubber, and living in a cold sea, it needs food for energy to keep warm." When an adult observer mentioned the similar case of the hummingbird's need for a great deal of food, this student caught on to something akin to the notion of metabolic rate, a concept he introduced in all subsequent discussions. The notion of metabolic rate, seeded by one student, quickly migrated throughout the classroom, was appropriated by many, came to form part of the common discourse, and eventually made its way into the class book on endangered species.

As a further example, a group of girls studying whales became interested in fertility rates and the fate of low-birth-weight babies. They discovered that one reason that certain species of whales are endangered is that their reproduction rate has slowed dramatically.

The same was found to be true of sea otters. These students introduced the concept of declining fertility rates into the discussion, and it was taken up in the common discourse in two forms: simply, as the notion of the number of babies a species had, and more complexly, as the notion of reproductive strategies in general. The skilled teacher appropriates students' spontaneous interest in the common problems of endangered animals—amount of food eaten, amount of land required, number of young, and so on—and encourages them to consider the deeper general principles of metabolic rate, and survival and reproductive strategies.

The Unintended Curriculum

Because students are free to direct their research efforts broadly, each group of students develops an idiosyncratic set of concerns in which they choose to major. We will trace one set of issues that occupied a mixed fifth and sixth grade class (1992–93) for an entire semester: the spread of disease by mosquitoes.

The entry activity for a unit on endangered species, the anchoring events if you will (Bransford, Sherwood, Hasselbring, Kinzer, and Williams 1990), was a whole-class treatment of two pieces of literature: an expository text, "Saving the Peregrine Falcon" by Caroline Arnold, and a play, "The Day They Parachuted Cats into Borneo" by Charlotte Pomerantz. The students used reciprocal teaching to help them understand the endangered status of the peregrine falcon and the role of DDT in contributing to it. Simultaneously, we capitalized on the students' skills of dramatic play and art by having them enact and illustrate the play—which essentially describes the disruption in a food chain brought about by the introduction of DDT to eradicate mosquitoes. Through sociodramatic play (Heath 1991), the students were led to consider a biological theme that required deep understanding.

Shortly after these activities, an important idea was seeded by a student on "parents' night," a meeting where the students introduced their parents to the participant structures of the project. Students were, in effect, the teachers, while the adults were the students. The discussion centered around the use of DDT and other chemicals in combating malaria. One extremely confident student teacher informed the group that, like malaria, AIDS can be spread by mosquitoes. No one in the group argued with this statement. One of the authors (Brown), also in the group, then attempted to squash this spread of misinformation by arguing that this was not so. Challenged for her evidence by the student, she could manage only a feeble, "I saw it on television," the type of evidence justifiably impermissible in these classrooms. In the ensuing discussion, the child theorist clearly won the day by

recourse to analogy and theory, "It's the same as with needles, infected blood gets into the needles and then spreads AIDS to another user—mosquitoes bite an infected host and then bite a healthy person—the blood commingles." Even his language was technical and impressive. This young theorist also made recourse to epidemiological data by arguing that the incidence of AIDS is higher in places where there are more mosquitoes, such as Florida and Africa. And to cap his argument, he introduced a little conspiracy theory, namely, that the CIA knows all about this but is repressing the evidence.

The next event followed immediately after parent night. The student theorist and the adult biologist called the San Francisco AIDS Hotline to find out whether, indeed, AIDS could be spread by mosquitoes. As it turns out, this is the third most frequently raised question for the hotline. The hotline operator answered from a crib sheet replete with deep biological terminology that neither the student/teacher interrogators, nor the hotline respondent, fully understood.

The information received from the hotline was as follows (from biologist Doris Ash's field notes):

> AIDS and Malaria are completely different in the way they are transmitted. The malaria *Plasmodium* parasite needs to live in the mosquito in order to complete its life cycle, and it has a very complex life cycle involving two hosts, a human and a mosquito. This is *not* true of AIDS.
>
> Where arthropod vectors (carriers, such as mosquitoes, ticks, fleas, etc.) are concerned, the parasite that causes the disease needs to both increase its numbers within the vector and also exit from it efficiently. This is true for malaria, but it is not true for the AIDS virus.
>
> With malaria, the parasites multiply, then concentrate in the salivary glands. When the mosquito injects the next victim, the parasites pass into the victim's blood. No such model exists for AIDS.
>
> During the decade that AIDS has been multiplying in the USA, researchers have been unable to locate multiplying HIV in mosquitoes and other anthropods, nor have they observed the virus in a place where they can exit the arthropod host.
>
> It should be noted that the mosquito does not inject blood into humans; it only sucks blood out of them. It does inject fluid from its salivary glands. Since the *Plasmodium* lives throughout the mosquito digestive system and migrates to the salivary glands, the *Plasmodium* parasite is injected into humans by carrier mosquitoes. To date, no animal intermediary has been identified with AIDS transmission.

Table 9.2
Seeding, migration, and appropriation of biological topics over a semester of student-directed inquiry

Student questions:	Bring up issue(s)
Do large amounts of DDT depress immune function?	Immunity and resistance.
If a human has malaria, can it be transmitted?—Can a baby get it inside the body?	Holoendemic areas vs. areas of new infection. Areas of endemic disease = high immunity. Immunity passed on to fetus. If first time infection, fetus at high risk.
What about babies outside the body?	After initial six month immunity, children 1–4 at high risk. Some children survive repeated bouts and develop immunity. The notion of vaccination.
In places in Africa with lots of malaria, is there more AIDS?	Epidemiological question: Answer is no.
Does plasmodium need mosquitoes to reproduce?	Transmission mechanism.
Does AIDS need mosquitoes?	Answer is no.
If they eat warm blood, why aren't they warm-blooded?	Warm- vs. cold-bloodedness
This is a clarification question. How does plasmodium adapt to warm blood?	
Do mosquitoes have cold or warm blood?	
Mosquito sucks blood out, spits saliva in?	Factors about blood clotting.
Does plasmodium go into the placenta?	Transmission mechanism.
If a child has it, and it grows, does the malaria get stronger and stronger?	Biological magnification.
If a mother breast feeds baby, can it get it?	Low possibility of AIDS spread through beast milk.
Do mosquitoes pass malaria on to young, or are they born with it?	Chicken/egg problem. Malaria around since recorded history.
What started it?	
Why didn't ice age kill it, like dinosaurs?	Mutation, drug-resistant strains.
In Kenya, people who have sickle-cell anemia don't get malaria as much?	Discussion of sickle-cell anemia as a protective factor.
Red blood cells are usually round. If you have sickling, your blood cells are like a sickle.	Sickle cell anemia. Red blood cells. Hemoglobin.
How do you get sickle cell?	Genetic transmission, recessive genes.

Table 9.2 (continued)

We heard that plasmodium eats what is called hemo . . . hemoglobin. What's hemoglobin?	Discussion of hemoglobin. Oxygen lack. Fever. Weakening. Shape of blood cells.
Ravaged blood cells clog the capillaries, deprive the brain of oxygen?	Brain/oxygen relation.
Why do babies die within a few hours of getting it?	Blood/oxygen/brain relations.
How do you get sickle cell? Is it in genes?	Genetic transmission. Genetic counseling. Genes, Nucleus, etc. Beginnings of DNA and gene altering.

Experiments with mosquitoes ingesting blood containing HIV indicate that they are not carriers, and epidemiological studies of AIDS-infected areas with mosquitoes do not indicate higher rates of AIDS than AIDS-infected areas without mosquitoes. If mosquitoes carried AIDS, for example, African children would have it in the same proportion as adults, but this is not the case. Since these children play outside and receive repeated bites, they would be expected to have AIDS if mosquitoes were carriers. However, this is not the case. In areas where there are both mosquitoes and AIDS, the incidence of AIDS is lower in children and adults over 60.

AIDS is transmitted most easily through direct transfer of blood or via vaginal and seminal body fluids. It is least likely to be spread via saliva. A human would need a large quantity of infected saliva in order to be in danger of transmission. To date, there are no proven cases of AIDS transmission via saliva. [Distillation of AIDS Hotline information, from Ash and Brown 1993, and work in progress]

Complex ideas indeed, but this was the starting point that fueled a semester of sustained inquiry, highlights of which are featured in table 9.2.

We do not have space to detail the natural history of these ideas in the conventional way. Small-group and whole-group discussions, written documents, and so forth are too extensive for inclusive. Instead in table 9.2, we trace the student questions (in approximately verbatim form) and the biological issues that the questions led them to discuss. These are but a few of the questions raised by students in their search for deeper understanding of an issue of general concern, the spread of AIDS.

The discussion of sickle-cell anemia was introduced by a student knowledgeable about the topic, as she had sickle-cell anemia herself.

S1: How do you get it?

S2: Sometimes it's in the genes. My mother gave it to me.

S3: Like if you kiss her?

S4: No, it's like in your genes, like you great grandmother could have had it. Like you were in your mother's womb, you would have gotten it.

S2: No, before that, in the genes.

S4: What are genes?

S6: Like what is in the blood. Like N.'s parents are really tall, so she is really tall. My mother has brown hair, so I have brown hair.

S7: Genes are little things that are inside the nucleus which controls the cell. It depends—like what kind of cell it is and how it responds. Nucleus is like a little brain. Genes live inside the nucleus when the sperm and egg are forming one cell—then they reproduce the genes [pause] we better look this up again to get clear.

The discussion on the role of hemoglobin was motivated by both the sickle-cell anemia discussion and by a Newsweek article, "The Endless Plague" (January 11, 1993), brought in by a student. The biologist reported that in twenty years of teaching at all levels including college, this was the first time she had taught about hemoglobin to students who had a reason for wanting to know!

Success of the Program

Knowledge Building

We will concentrate first on the acquisition of biological knowledge. In short, did the students learn anything? And how would we know if they did? We use an extensive battery of static and dynamic pretest and posttest measures as well as on-line indices of conceptual change. We augment pretest and posttest scores by the use of portfolios and student products. The database is extremely rich, and we will concentrate in this chapter on the more traditional pretest/posttest tasks and extension activities of knowledge utilization.

All students receive short-answer quizzes on the entire theme before and after each unit. Half of the items are generated by the student

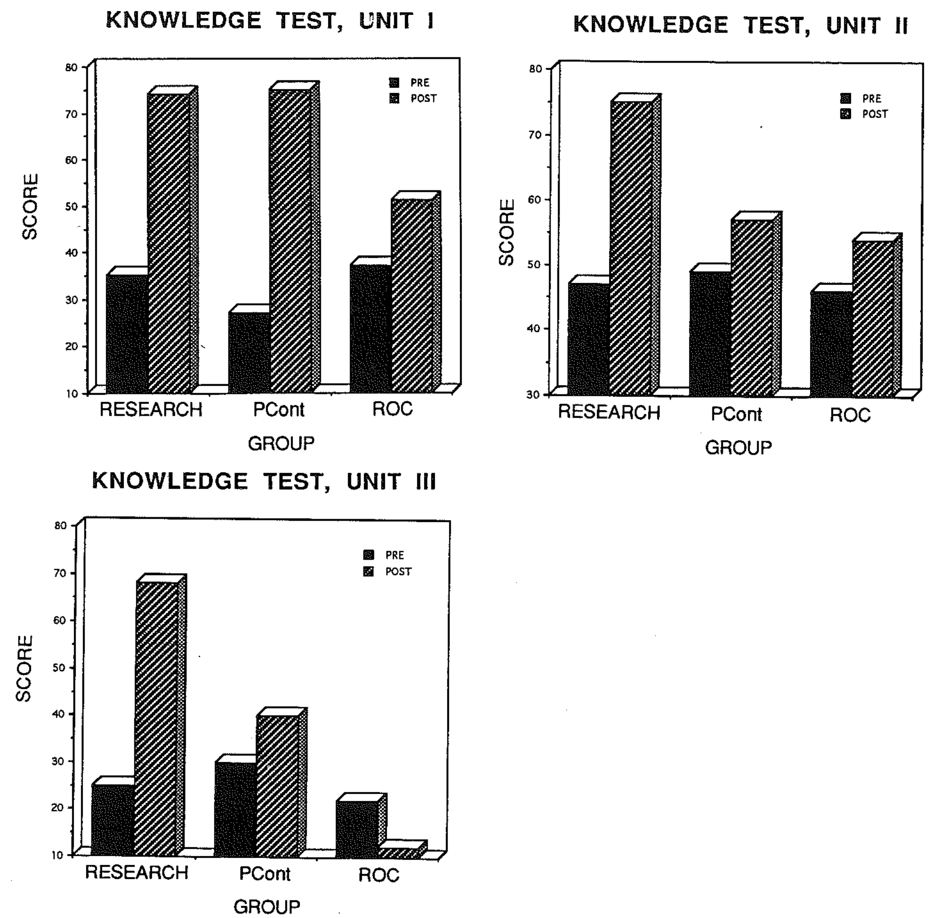

Figure 9.2
Results of unit content knowledge tests in a fifth and sixth grade full-year intervention. PCont = partial control group, who were students in the first semester (unit 1), then taught by their regular classroom teacher. ROC = a read-only control group that read the key materials but did not research.

research teams and half by our staff. The results of short-answer quizzes for one full-year intervention with fifth and sixth graders are shown in figure 9.2. Students in the research classes were compared with those in a partial control group (PCont) treated exactly the same as the research classes for the first semester (unit 1), and then taught environmental science by their regular science teacher. The partial control group had exactly the same access to books, videos, computers, and so forth, as the research classes. As figure 9.2 shows, the two groups did not differ from each other on unit 1, where they were, in effect, both research groups, treated exactly the same; but the children in the research classrooms outperformed the partial control group on both units 2 and 3. A read-only control (ROC) group, who read the key materials but did no research performed poorly throughout. These "quick assessments" given to all students assure us that domain-specific content is retained better by students in the research classrooms.

Clinical Interview. The next question is, can the students use the information flexibly? Students differ in their level of understanding and in the confidence with which they hold opinions. To test this we have developed a clinical interview (Ash and Brown 1993) consisting of a series of questions designed to be sensitive to the bandwidth of competence within which each individual student can navigate (Brown and Reeve 1987). To map the window of opportunity for learning, the interviewer raises a series of key questions, first eliciting basic expository information—for example, what does the student know about the food chain? If the student cannot answer, the interviewer provides hints and examples as necessary to test the student's readiness to learn that concept. If however, the student seems initially knowledgeable, the interviewer questions the stability of that understanding by introducing counterexamples to the student's beliefs ("Is a mushroom a plant?" "What about yeast?") and, if appropriate, asks the student to engage in thought experiments that demand novel uses of the information. For example, a student who has sorted pictures into herbivores and carnivores, and justified the choices, may be asked, "What would happen on the African plain if there were no gazelles or other meat for cheetahs to eat? Could they eat grain?" Some students are surprisingly uncertain about this, suggesting that cheetahs could eat grain under certain circumstances, although they would not live happily. Some even entertain a critical-period hypothesis—that the cheetah could change if it were forced to eat grain from infancy, but once it reached adolescence, it would be too set in its ways to change. Only a few invoked notions of form and function, such as properties of the digestive tract, to support the assertion that cheetahs could not change within their lifespan. In figure 9.3 we see one student's pre- and posttest attempts to negotiate such a thought experiment. These extension activities of thought experiments and counterexamples are far more revealing of the current state of students' knowledge than their first unchallenged answers.

Critical Thinking about Content. We see the same benefit of being in the research classroom on novel application questions, such as "Design an animal to fit the following habitat" (desert, tundra, or rain forest)

THOUGHT EXPERIMENT

Question: Could a cheetah change from a meat diet to a vegetable diet and survive?

First interview	Six months later
S: . . . well I mean if people can, like, are vegetarians, I mean I think a cheetah could change . . .	S: No. No, their digestive systems isn't good enough . . . it's too uncomplicated to digest grasses and also their teeth wouldn't be able to chew, so then the grass would overpopulate . . . and the cheetah dies.
When asked how this might happen:	When asked if the baby cheetah could survive by eating grass, the student asserted that they would probably be the first to die.
S: Well . . . just to switch off, but um, it would be easier for them to change on to plants than it would be for me; if I had been eating meat . . . because there would still be meat around for me to eat, but for them there wouldn't be . . . so if they wanted to survive, they're going to have to eat grass.	Thrown a novel twist on the old question -- whether the gazelle might be able to eat meat if there were no longer grass, the newly confident student favored the interviewer with a broad smile and said:
When asked if it would be easier for a baby cheetah to eat grass:	
S: Well, if it was a baby, it would be easier because it could eat it . . . it would be right there, it would just have to walk a little bit to get it . . .	S: Nice try . . . the digestive track of the deer is too complicated and also the teeth wouldn't be able to grind meat.

Figure 9.3
Thought experiment from a sixth grader showing changes in reasoning

or "Design an animal of the future." The sixth graders in the research classroom outperform control students in the number of biologically appropriate mechanisms they include in their designs (such as mechanisms of defense, reproductive strategies, etc.). Over time the research students introduce more novel variations of taught principles along with more truly novel ideas as can be seen in figure 9.4. For example, the class had discussed the notion of mimicry as a defense mechanism. In a response-scored taught/novel, one student said that the eggs of his animal were placed in a line and the markings made the eggs look like a "full grown cobra," a novel use of the mimicry principle. Another student incorporated the notion of behavioral mimicry that had

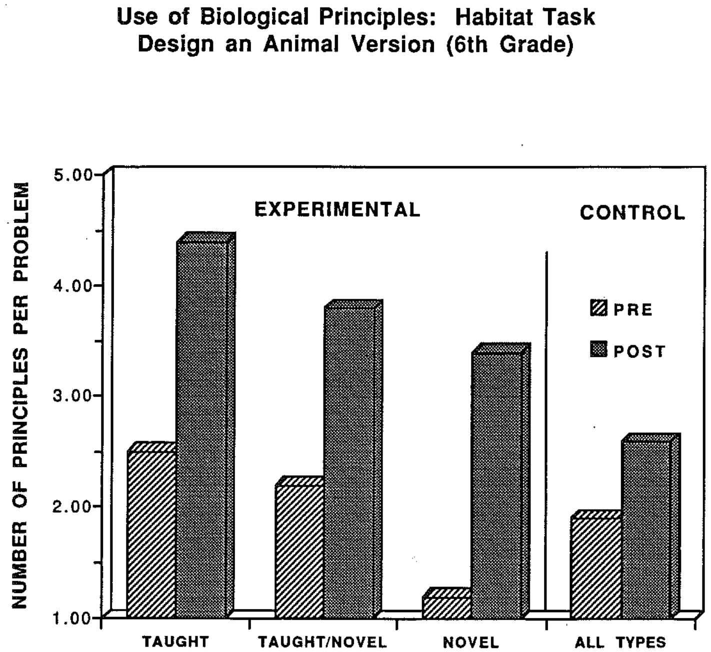

Figure 9.4
Pre- and posttest scores on a transfer test: Design an animal to fit a habitat

not been taught, still another introduced the concept of a predator's injecting a poison to which it was itself immune, so that the predator could safely devour the stunned prey.

Responses to clinical interviews, "what if" thought experiments, and analogy and transfer tests tell us a great deal about the status of the child's accumulating knowledge and ability to reason on the basis of incomplete knowledge. We regard them as fruitful avenues for promoting and evaluating students' ability to think critically about knowledge, an antidote to the stockpiling of passive, inert knowledge (Whitehead 1916).

Reading

Although billed as a science curriculum, the program of research is very much an extension of the original reading comprehension work that began with reciprocal teaching (Palincsar and Brown 1984). Our main "transfer" data, therefore, take the form of: (1) improvement in students' reading comprehension scores on materials outside the domain of study and (2) gradual acquisition of increasingly complex

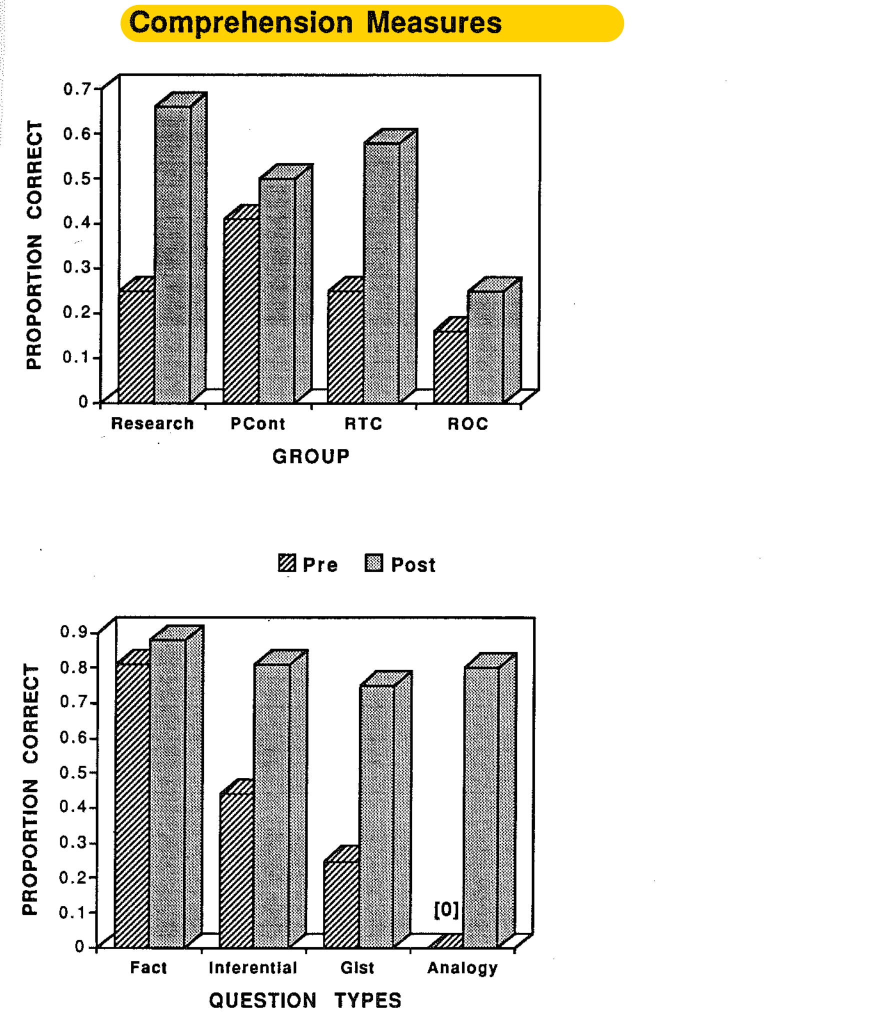

Figure 9.5
Reading comprehension measure in domain outside biology. PCont = partial control group as in figure 9.2. RTC = a reciprocal teaching control group. ROC = read-only control.

forms of argumentation and explanation strategies. We will limit ourselves here to a few representative samples.

We begin with an example of fifth and sixth graders' performance on criterion-referenced tests of reading comprehension. The data are from a full-year study, where we worked with approximately ninety students (Brown and Campione 1990). At the beginning and end of the year, students read age-appropriate expository passages unrelated to the curriculum and answered a set of questions from memory. These data are shown in the top half of figure 9.5. Students in the research classroom outperformed a comparison group reading the same passages via reciprocal teaching, even though the reciprocal teaching control group, (RTC) was given at least twice as much practice in the collaborative reading procedures and in taking tests of this nature. A read-only control (ROC) failed to show improvement. We also included a partial control group (Pcont) consisting of sixth graders who were treated the same as the experimental group for the first semester but taught by their regular classroom teacher after that. They also failed to achieve the same gains.

On each passage students were asked four fact and four inferential questions, together with a gist question requiring them to summarize the main theme of the entire passage, and an analogy question where they were asked to solve a problem analogous to the problem solved in the target passage. The bottom half of figure 9.5 shows the differential improvement according to question type for the research students (we include data from only those students tackling grade-appropriate texts). By design, students began scoring well on simple fact-based questions (to ensure that they achieved some success); as a result, there was no improvement on this measure. On inferential, gist, and analogy questions, however, there was significant improvement. In particular, regular practice greatly improved the students' ability to use analogous information to solve problems; that is, practice creates a mind-set to reason by analogy (Brown and Kane 1988).

Argumentation Skills. Increasingly powerful comprehension-extending activities occurred in the student dialogues, such as those shown in table 9.3. The use of deep analogies and causal explanations increased over time. Explanations were more often supported by warrants and backings (Toulmin 1958). The nature of what constitutes evidence was discussed, including a consideration of negative evidence. A variety of plausible reasoning strategies (Collins and Stevens 1982) began to emerge. Argumentation formats developed, in which different points of view and defensible interpretations were compared. The nature and importance of prediction evolved, with students going beyond predictions of simple outcomes to considering possible worlds and engaging in thought experiments about them.

During the year, students progressed from using surface similarities (simple) to a reliance on deep analogies (advanced). For example, children initially make surface analogies, such as between human eyes

Table 9.3
Discourse activities

Analogy:
To note recurrent theme
To explain mechanism
Causal explanation:
Impasse driven
Resolving inconsistencies
For deeper understanding of mechanism
Explanation and evidence:
Claims and premises
Warrants and backings
Negative evidence
Argumentation:
Different points of view
Different interpretation
Predictions:
Of possible outcomes
Of possible worlds
Of perturbations in the system
Tought experiments—What if? Imagine that, etc.
Plausible reasoning

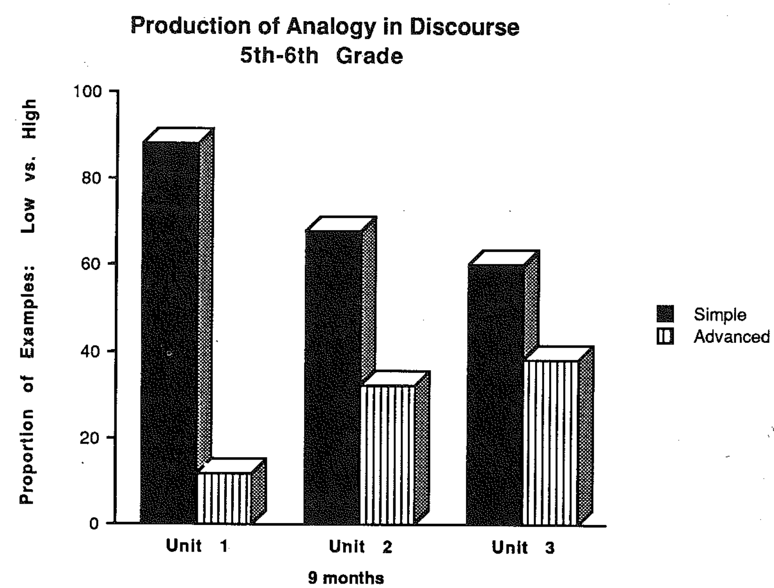

Figure 9.6
Production of analogy in the discourse

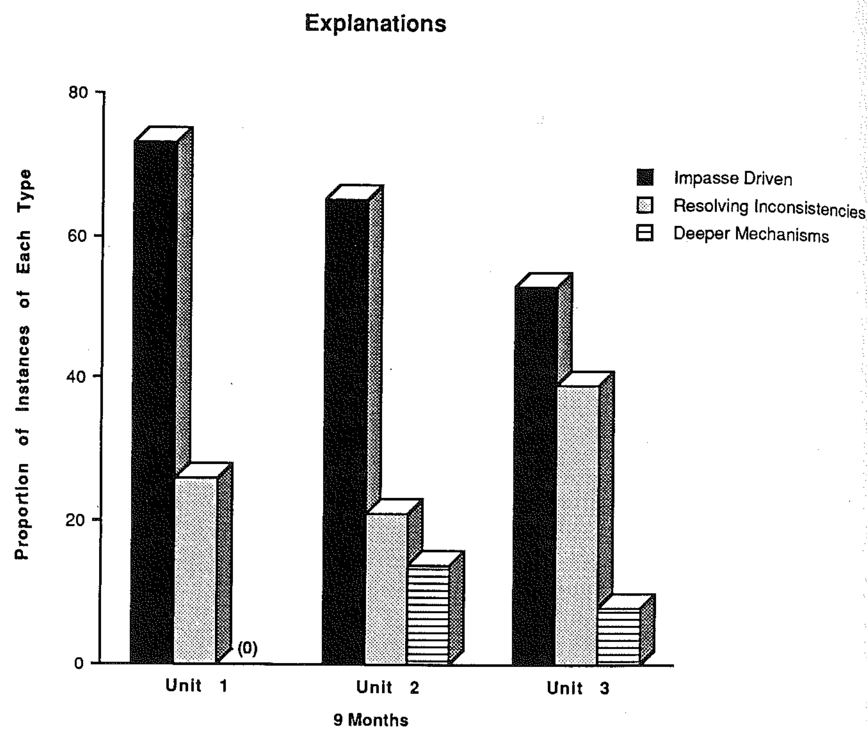

Figure 9.7
Condition of production of explanations in the spontaneous discussion

and the headlights of a car (surface), while later they make the analogy between a car's engine and the human heart (deep). With increasing knowledge, children progress from accepting superficial analogy to using deep analogy to explain mechanisms. They question initially acceptable surface analogies (such as "plant stems are like straws"), then come to prefer analogies based on deeper understanding of the underlying biological mechanisms ("Plants are food factories"). This progression is shown in figure 9.6; over time, students make more effective use of analogy in their discussions. They use increasingly advanced analogies, both to help them learn new material and to communicate their new understanding to others.

There was a similar development in students' recourse to, and use of, causal explanations, where they go beyond specific facts and set out to understand relations among facts through attempting to explain the relevant mechanisms. As shown in figure 9.7, in the first unit of the year, students attempted to generate explanations when faced with

an impasse or a breakdown in comprehension, that is, they sought an explanation in response to a comprehension failure. Later, students resorted to explanations in attempts to resolve inconsistencies. Finally, students used explanation spontaneously, in the absence of comprehension failure or obvious inconsistencies, as they continually revised and deepened their understanding of complex causal mechanisms (Brown 1991).

Extending the Learning Community

Inside the School

In order for the program to run optimally, adults are needed to lead jigsaw and reciprocal teaching seminars, but of course having a large number of adults available to serve this function is just not feasible. We try to conduct the intervention in such a way that dissemination across schools would be possible. As a rule of thumb, we have no more than two adults, the equivalent of a teacher and an aide, interacting with the children. Other adults in the classroom serve purely observational or data-collection roles.

For these reasons we rely heavily on the expertise of the children themselves. We use cross-age tutoring, both face-to-face and via electronic mail, and we also use older students as discussion leaders guiding the reciprocal teaching groups of younger students.

Cross-age Training. Cross-age tutoring provides students invaluable opportunities to talk about learning. Cazden (1988) argues that there are four specific benefits of discourse among peers. First, peer discourse may act as a catalyst to other ideas. Talking with other students provides access to a variety of thoughts and perspectives. Second, peer discourse may allow students to adopt complementary roles so that when working together, they may draw on each other's strengths. Third, peer discourse gives practice in building a relationship with an audience. Students learn to question each other and make ideas clear to others through peer talk. Finally, peer discourse grants the opportunity for "exploratory talk," as opposed to producing "fully intact" thoughts. Bruner (1972) suggests that the higher goal of tutoring is the "building of community," where both the tutor and tutee get a "better sense of what it is to share." Peer and cross-age tutoring give students responsibility and purpose, and reinforce collaborative structures throughout the school.

Our cross-age tutoring program (Nakagawa and Brown, work in progress) involves fifth and sixth grade students working with second and third graders. The tutors receive a four-week training program.

The class discusses questioning, listening, relating personal experiences to text, and so on. In addition, the experienced fifth and sixth graders are reminded of: (a) reciprocal teaching procedures; (b) guided writing using computers; (c) pair editing; and (d) the content area of interest to both ages (note that both older and younger students focus on endangered species in their environmental science units). Finally, the older students are introduced to the rudiments of ethnographic methods—what to look for, field notes, interviewing tutees, and so forth (Heath and Mangiola 1991).

We intend to extend our work on cross-age collaboration by instituting a "one room schoolhouse" series in which students will be

Table 9.4
Cross-age tutoring (first session together; 31-page transcript)

Cast:

Fl	Fifth grade facilitator
Cr, Ke, Je, Da	Third grade returning students
Ri Ne, Tr	Third graders new to program

Tr Presents (p. 22 of transcript)
[Tells group of her urban wildlife: monkey flower and wild carrot Questioning begins]

Je: When the uhm, when the monkey flower dies, does it turn all brown and all the feathers come off? I mean, you know, the leaves. Whatever it is.

Tr: It limps. It goes like that [body movement of limp plant].

Ri: What does it eat?

Tr: Water. It eats water and, this is how you make its food. With air, sunlight and water.

Ri: What does the wild carrot eat?

Tr: It eats the same thing, and it can eat dirt too. That's what it eats—

Ke: Does you animal, I mean plant, need the ah, ah, the soil? Does it need soil?

Ne: Water.

Tr: [Calls on fifth grade facilitator, who has her hand up] Fl.

Fl: Plants don't eat soil. They don't eat soil at all. There was this experiment that was—

Je: Soil is dirt. That's where they growing.

Fl: They just grow in it, but they don't eat it. They make their own food. You know how, like how the carbon dioxide and everything, they mix that in, and that act is called photosynthesis. So they don't—

Tr: How do you spell that?

[Fl writes the word on paper, gives to Tr who copies it into her field notes]

Fl: For one thing, there was an experiment—a gallon, I think about five gallons of soil was put under a redwood tree that started growing, and as soon as it was real, real tall, the scientist took the barrel of soil away, and found out that only about two ounces were taken away. Only about two ounces were all.

Tr: It doesn't need the earth for food? It makes its own?

grouped together because of common research interests, rather than age, for several periods a week. All students interested in, say, urban wildlife, will meet as a club, all those working on rainforest destruction will be in another room, and so forth.

Students as Discussion Leaders. We also train our older students to act as discussion leaders. Although we experience some of the same difficulties with students as with adult teachers, notably the tendency to be too directive, fifth and sixth graders are remarkably facile at leading discussions. They mimic activities modeled by their own adult teachers and enact them with their young charges. Again, children themselves introduced both examples of thinking activities and content area knowledge into the wider community. An example of this can be seen in table 9.4, where a fifth grader tries to dispel the common notion in her second graders that plants eat soil as food.

Guest Teachers. As we work primarily with grade school teachers who are not subject-area specialists, we provide additional support in the form of outside subject-area experts who interact with the teachers and students, either in person or electronically. In table 9.5, an outside expert, a biologist, begins her second benchmark lesson by modeling thinking and research skills, and introducing biological ideas and terminology. In response to the student question, the teacher not only introduces the term *sexual dimorphism* but also points out that she has been thinking about the problem all week (2,5). The exact answer is not in the books she has, and she invites the students to join her in a thought experiment about how a biologist might reason this through (5,6). In utterance 6 she explicitly poses a thinking challenge and introduces the notion of advantages and disadvantages of a species adaptation. In utterance 16 she entertains a students' erroneous suggestion that the larger size of the female might allow her to have more eggs, a suggestion that is rejected by a student (17) by recourse to negative evidence.

Two weeks later they return to the topic; excerpts of the hour-long discussion are shown in table 9.6. Again, while accepting a student's correct solution (2), the teacher talks about her own thought process (3) and directs them to a crucial part of their readings (4) illustrating the notion of competitive advantage that the students understand.
A final example of teacher modeling that formed part of the third benchmark is what to do when there is disagreement:

> *Jo:* Do the peregrine falcons eat any other kind of prey besides birds?
>
> *Lav:* They eat prey, but I mean they eat, like meat.

Table 9.5
Discussion from second Benchmark lesson

(1) *R:* There's this one topic that I really want to find out about, is why female peregrine falcons are larger than males.

(2) *T:* I know that question has been on your mind; you've mentioned it three different times. It's been on my mind since Tuesday. Do you know the first thing I did when I got home? I got all my biology books out, and the topic I looked up is sexual dimorphism. I have my biology hat on. Right now I'm talking as a biologist. And I'm going to use some biological terms. Sexual has to do with male and female, right? "Di" means two. "Morph" has to do with how you look. It really means form.

(3) *T:* What's the question? The question was, R?

(4) *R:* Why are the female peregrine falcons larger than the males?

(5) *T:* I said OK, the male and female, having two looks, male and female. In my books do you know what they said? They said usually the male bird is more gorgeous and has better feathers and is red and blue. And the female is kind of drab. Drab means kind of dull looking. I said, "Huhh?" That's true right, but that's not the peregrine falcon. In your RT texts, it specifically said they look pretty much the same. Right? And the female is bigger. So we're not talking about pretty males and drab females are we? But the books said this: when you have pretty males and drab females, usually the male does not help take care of the babies. Hint. And I said that probably tells me that the male peregrine helps take care of the baby because he looks like the female. So then I said, "T, you're a biologist. How would a biologist think this problem through? Let's think like a biologist."

[Students make suggestions, mimic putting on biologist hats]

(6) *T:* Now here's a new thinking challenge for you. We need to think what is the advantage, the pros, of being bigger, and what are the disadvantages, the cons. The pros and cons. And in the biological world you add those pros and cons up, and usually you weigh them. Let's think about some advantages and disadvantages. And here is where we are all on the same ground I couldn't find it in a book, and I'm asking [student teachers] to help me because none of my books said anything about it. Really think, think, think. What might be an advantage of being bigger if you were a female peregrine falcon? Forget the male for now.

(7) *El:* She can scare people away because she's bigger.

(8) *T:* Scare away predators. Can I use that word? Is that OK, El?

(9) *El:* Yeah.

(10) *N:* She can keep the babies warmer?

(11) *R:* Protect her babies.

(12) *T:* What's a disadvantage? El?

(13) *El:* Oh, DDT has a better chance of hitting her because she is wider.

(14) *Al:* Well, if the female has DDT how is it going to have babies? La.

(15) *La:* This is an advantage because if she is bigger therefore she can produce more babies because she has enough womb to make a lot more babies than if she was smaller than the male.

Table 9.5 (continued)

(16) *T:* What La just said is what I came to, but I don't know if I'm right. In the car this morning I said well, if all things being equal it's OK for the female to be bigger and if she is bigger can't she lay more eggs? If she lays more eggs, can't she have more babies. If she has more babies, isn't she going to survive and be more successful?

(17) *Ma:* She's not going to have more babies because look, humans are bigger than peregrines, and they only have one baby, sometimes twins. And what about elephants? They only have one baby every three years. N?

Table 9.6
Two weeks later: Third Benchmark

(1) *El:* . . . like because all birds of prey are called raptors, and a lot of the raptors are bigger than the . . . have females that are bigger than the males.

(2) *Ta:* Since the female is larger she's able to feed on a larger prey than the male is.

(3) *T:* All right now, we are talking about survival, having babies and not dying, and getting food, right? We talked about advantages and disadvantages. That's a big idea. Today, I have another big idea in mind. Our conversation two weeks ago had a lot to do with reproduction and babies and protecting and warm, right? But we all forgot something, including me. So I went home Tuesday night and I thought and thought and thought. Something's missing here.

[Discussion by students]

(4) *T:* All right, let's direct our eyes back to our food chain. [Peregrine falcon food chain designed by students and displayed on board.] Now here's my thought process yesterday. Biologist's hat. I shared this with Ann [ALB] yesterday, and with Stella [classroom teacher] today. Now catch this. What if, because the female is a third larger, in their territory—the place that they live—what if she can take advantage of eating things like ducks and pigeons, which are relatively *large* birds, and the male, because he's a little smaller, maybe he can take advantage of eating relatively *small* birds, how might that give an advantage? Now think this through please. I want some thoughtful processes here. How might this help?

(5) *Lee:* Well, it would help them because they could, they could use a smaller place to live, like a territory. Because if the male, if it eats different food from the female, it would be less likely to run short on food. Uhm—

(6) *Ned:* It would make it better for them because they would like have, both of them go out and hunt at different times. It's like the female could bring back bigger prey, the male could bring back smaller prey. And they could put it together and have more food.

> *T:* Uh-huh. They eat meat, which is prey—meat. Do they eat any other kinds of animals besides birds? Ned.
>
> *Ned:* Yes, they eat like squirrels and stuff. And little rodents.
>
> *T:* Not that I know of, actually. Can you prove that, Ned? That would be good if you could prove that. Because I thought I read that—in your, in the book—that they only eat birds. I thought I read that they *only* eat birds. This is the question. We better have a little question board here. Do they eat anything besides birds? That's important for us to consider, isn't it? Can somebody write that down in their journal please? Ned and I are disagreeing. And I'll try to get some proof, you try to get some proof. All right? Now where could we go to get the proof?
>
> *Lav:* QuickMail
>
> [Kids list examples of available sources, including outside experts]

Extending Community beyond the Classroom Walls

We turn next to the use of QuickMail to extend the research community beyond the classroom walls, thereby creating richer zones of proximal development for community members. For example, consider the following exchange between a biologist (MJ) and a group of students (Da 4 Girlz). The interaction was initiated by the students, who queried the status of hibernation for incarcerated bears.

> Our major questions are (WHAT HAPPENS TO THE BEARS THAT LIVE IN THE ZOO IF THEY CAN'T HIBERNATE?). DA [the science teacher] said that they don't need to hibernate because they are fed every day. But she said that was only a thought so I am asking you to please help us by giving us all you know and all you can find.

MJ responded with some information; admitting that he didn't really know the answer, he suggested an hypothesis and provided a phone number for the group to find out more information on their own. Throughout the interchange, MJ systematically seeded three pieces of information critical for an understanding of hibernation: the availability of resources, longevity, and warm- vs. cold-bloodedness.

> You probably think about hibernating in the same way as you think about sleeping, but they aren't the same. Bears hibernate in response to the weather conditions and the availability of food. If the conditions are reasonably fair (not too cold) and food is available the bear probably won't hibernate. I don't know, but I hypothesize that during the times when bears would usually hibernate, bears in captivity are probably a bit slower, still showing signs of their tendency to hibernate at that time of the year.
>
> How could you find out if my hypothesis is true? (Hint: Knowland Park Zoo, 632-9523)

The topic is then dropped by the group but taken up by one group member (AM), who is "majoring" in hibernation and wishes to know about hibernation patterns in insects. She inquires to the network in general.

> I was wondering if you can find out an answer to this question. The question is does insects hibernate? The reason why we ask that is because MR [classroom teacher] read a book named Once There was A Tree. And in it, it said something about the insects slept in the bark of the tree when winter came. then when spring came they got up and did what they usually do till winter comes then they start all over again.

Receiving no response, the student then addresses MJ directly about the topic. As a gesture of good faith, she begins by offering some facts of her own before asking for information:

> Bears hibernate because what ever they eat is gone during the winter (like berries) and they can't eat so that's what hibernation is for. It is for them to get away from starvation. So what does truantula's eat? Can they always get their food? If they can't get their food would they have to hibernate or die? Could we ask somebody that knows about insects?

MJ responds with another prompt to encourage the student to take the initiative and contact experts, this time at the San Francisco Zoo, pointing out that the contact person there is ready and willing to help. The persistent AM sends yet another request, and MJ reenters the fray. Following a lengthy paragraph on the reproduction and survival strategies of insects, he continues with a series of questions intended to push the student to further and further depths of inquiry, a typical strategy of guides in a zone of proximal development. In this communication, he introduces the notion of longevity, prompting AM to consider the fact that if an insect lives only one season, hibernation would not have much survival value for the species!

> So you ask . . . what does this have to do with your questions about hibernation? Consider the difference between the life style of your typical mammal and that of the typical insect. Why is hibernation important to some mammals? Why might hibernation not be a successful strategy for most insects? Some insect,

> such as tarantula, live for 10 or more years. Do you think that they might hibernate? How might their life style be different from that of other insects.

Resisting this lead, AM again adopts the easier path of asking for direct information. "I'm not really sure if tarantula hibernates. What do you think?" to which MJ again responds with some critical information about warm-bloodedness.

> I'm really not sure either. I do know that insects are cold blooded which means that they don't have a constant body temperature. This means that they depend on warmth from the sun or other objects in order to become active (move around and hunt). This happens pretty much every day. As the sun sets and it gets cold and cold blooded animals slow down. But hibernation is something that happens over a greater period of time (over a year rather than a day). Where do you think we could find out more about this question?

The interaction continued for several days. MJ gradually seeds the zone of proximal development with three critical pieces of information during this exchange. AM picks up on two of these features (availability of resources and longevity), although she never understand warm-bloodedness. QuickMail as a medium for sustaining and expanding zones of proximal development has exciting possibilities and is an essential feature of our learning environment, freeing teachers from the burden of sole knowledge guardian and allowing the community to extend beyond the classroom walls.

Strengths and Weaknesses of a Guided-Discovery Classroom

Strengths

Distributed Expertise. Reliance on the two modes of cooperative learning, reciprocal teaching coupled with jigsaw, ensures that expertise is deliberately distributed across the members of the classroom (Brown et al., in press). In addition, variability in expertise arises opportunistically. The ploy of increasing rather than decreasing diversity and of allowing many "ways in" to full or legitimate peripheral participation (Lave and Wenger 1991) increases the richness of the knowledge base on which the community can draw. Everyone in the community is an expert responsible for sharing his or her expertise with others. Both inside and outside school, students and teachers have access to circles of ever-deepening domain expertise.

Teachers Capitalize on Student Expertise. Teachers have at their disposal a variety of experts capable of peer and cross-age tutoring. Adult teachers are not the only source of knowledge. Many members of the community are knowledgeable. This knowledge can be harnessed to provide varieties of expertise, thus enriching the learning environment and at the same time providing opportunities for its members to take responsible leadership roles.

Multiple Roles are Modeled and Appropriated. Because majoring is encouraged, even teachers are free to reveal ignorance of certain topics and to model ways of overcoming that ignorance by consulting outside sources and continuing to develop expertise over sustained periods of time. Children are free to be domain experts, be that in the subject area under study, in the use of technology, or the role of social facilitator.

Actors and Audience. Everyone in the community is a teacher as well as a learner; everyone is at some stage an actor and an audience. The sense of audience for one's research efforts is an important aspect of the community. Audiences, be they adults or children, demand coherence; they push for higher levels of understanding; they require satisfactory explanations; they request clarification of obscure points. Students do not have to deal with a single audience, the teacher, as they usually do in school; the sense of audience is not imaginary, but palpable and real. Students are forced to teach what they know, and this is often the impetus for learners to recognize gaps in their knowledge that need attention before they take center stage again.

Sustained Complex Thinking. Students in these learning communities are capable of deep, sustained, complex thinking, both in whole-class discussions and in their small groups. Consider the following example of a group of second graders dealing with the food chain involving a colleague's imaginary animal:

> *S1:* And, um, since it's the top of the food chain that I told you about, it has no predator, so. The baby ocrawhale has flat teeth when it's born, and two years later it gets sharper teeth so it can eat meat.
>
> *S2:* What do the little fish eat?
>
> *S1:* [Impasse] Well, the little fish are the bottom of the food chain, *so they don't have anything to eat.*
>
> *S2:* Oh! But how do they stay alive?
>
> *S1:* They probably just survive by their wits.
>
> [Five minutes later they are still puzzling about the sustenance of the fish at the bottom of the food chain]

S4: Yea, They can't live on, they can't live without food, just like we can't.

S1: Um, first the babies in those fish may be about this small.

S4: But, still, they have to eat.

S1: But then they get older and bigger.

S1: Well, first it eats seaweed and then . . .

S4: Well, that's what you should have said at first, because you said it would never eat nothing. [Bell rings]

[The children continue the discussion after class, telephone each other about it (parent report), and S1 agrees to "fix it" in his revision.]

Sloppy thinking is not tolerated by even our youngest community members.

Weaknesses

Limited Knowledge Capital. Any learning community is limited by the combined knowledge of its members. Classrooms are constrained by four walls. Attempts to expand the knowledge capital of the community by recourse to libraries, field trips, and the like are as old as school itself. But even so, within traditional schools, members draw on a limited knowledge capital if the faculty and students are relatively static, or face jarring discontinuity if there is rapid turnover of personnel. Furthermore, both teachers' and students' expectations concerning excellence, or even what it means to learn and understand, may be limited if the only standards are local ones. Methods of extending the community beyond the classroom walls are needed to enrich and challenge the knowledge capital of a learning community.

Teacher Competence. A major problem with guided discovery is the load placed on the guide, the official teacher. Invoking comfortable metaphors such as the teacher as coach does not tell us how and when the teacher should coach. How can the teacher foster discovery and at the same time furnish guidance?

The role of guide in the discovery process is difficult to maintain. Consider the position for a teacher who knows something that the students do not. Here the teacher is in the position of making a judgment call about whether to intervene or not. The teacher must decide whether the problem centers on an important principle or involves only a trivial error that she can let pass for now. Consider the case of the teacher who does not know the answer, or one who may share the students' puzzlement or misconception. In this case, the teacher is first required to recognize this fact (which the teacher might

not be able to do), and, after admitting puzzlement or confusion, find ways to remedy it, for example by seeking help. This is not an easy role for many teachers; it requires them to admit that they do not know and seek help, thereby modeling this important learning strategy for their students.

Teacher as Critical-Thinking Model. In addition to guiding a course through the curriculum content, the teacher should also be a role model for certain forms of inquiry activities. If students are apprentice learners, then the teacher is the master craftsman of learning that they must emulate. In this role, the teacher models scientific inquiry through thought and real experiments. Ideally, children should witness teachers learning, discovering, doing research, reading, writing, and using computers as tools for learning, rather than exclusively lecturing, managing, assigning work, and controlling the classroom.

The teacher's job also includes efforts to model habits of mind by which children are encouraged to adopt, extrapolate, and refine the deep underlying themes to which they are exposed. As Bruner (1969, 126) argues, education

> should be an invitation to generalize, to extrapolate, to make a tentative intuitive leap, even to build a tentative theory. The leap from mere learning to using what one has learned in thinking is an essential step in the use of the mind. Indeed, plausible guessing, the use of the heuristic hunch, the best employment of necessarily insufficient evidence—these are the activities in which the child needs practice and guidance. They are among the great antidotes to passivity.

But again note this requires the expert guidance of a gifted teacher.

Misconceptions. Children "discovering" in our biology classrooms are quite adept at inventing scientific misconceptions. For example, they readily become Lamarckians, believing that acquired characteristics of individuals are passed on and that all things exist for a purpose. They overdetermine cause, the teleological stance, thus blinding themselves to essential notions of randomness and spontaneity (Mayr 1988). We encourage teachers to see these common problems as fruitful errors, way stations on the route to mature understanding that they can manipulate and direct in useful ways. Our teachers are also made aware of common misconceptions that students may harbor concerning, for example, the nature of plants or natural selection (Brumby 1979). Armed with this information, teachers are better able to recognize the occurrence of misconceptions and fallacious reasoning so that they may then introduce students to counterexamples or other challenges to their inchoate knowledge, for example, by having students who believe that plants suck up food through the soil conduct experiments on hydroponic gardening.

The Need for a New Theory of Learning

We argue that a major part of a research agenda such as the one described in this chapter is to contribute to a new theory of learning that would capture the richness of the environment and the flexible learning activities it engenders. This theoretical development is necessary for practical reasons as well. If one wants to disseminate the program on the basis of principles of learning rather than surface procedures, one must be able to specify what those principles are.

Dissemination is not simply a matter of picking up an innovative program and dumping it down in a new site unchanged. Even when we move from one class to another, the program undergoes significant change, depending on the interests of both students and teachers, the age of the children, the relative importance of literacy versus content knowledge, and so forth. Dissemination is a theoretical and practical problem of some complexity.

Any dissemination model consists of three overlapping parts: invention, diffusion, and consequences (Rogers and Shoemaker 1971). Change itself is of two main types: *immanent change* created within the social system and *contact change* created outside the social system in question. *Selective contact* occurs when people learn about a new idea and choose to implement it, and *directed contact* occurs when outsiders force the innovation to be adopted.

To date, our model of dissemination has been one of selective contact and immanent change, with teachers free to select new ideas and innovations based on their needs—*as long as they adhere to the first principles of learning on which the program is based*. As we expand our dissemination efforts to more distant sites, we will need to think deeply about this insistence that the first principles remain intact while allowing adaptation and modification as an organic part of the implementation process. This notion of "implementation as evolution (Majone and Wildavsky 1978) constrained by first principles" is our eventual goal.

First Principles of Learning. The development of a learning theory that can capture the essential features of our learning community is of paramount importance to this project. The development of theory has always been necessary as a guide to research, a lens through which one interprets data. But theory development is essential for practical implementation as well. Our dissemination attempts will rely heavily on our ability to specify first principles. In our past experience, procedures such as reciprocal teaching have enjoyed widespread dissemination: the term is used without the need to reference the originators. It has been picked up by researchers, teachers, and textbook publishers, and has become part of the discourse of the educational community.

If one looks closely at reciprocal teaching as practiced outside the control of the originators, however, the first principles of learning it was meant to foster are often lost, or at best relegated to a minor position. What is practiced are the surface rituals of questioning, summarizing, and so on, divorced from the goal of fostering understanding that the procedures were designed to serve. Teachers and students nationwide practice the "strategies," sometimes even out of the context of reading authentic texts. Rarely are the procedures modified and extended to enhance the learning principles upon which they were based.

It is the first principles, not the surface procedures, that we want to disseminate. And it is these that we wish to share with teachers, so that they are free to design or modify any surface activity in ways that are consistent with the principles. As we embark on more extensive dissemination efforts, it is necessary that we develop first principles of learning in such a way that they can guide dissemination and professional development, as well as inform our academic colleagues of our theoretical development.

The first principles of learning are by no means written in stone. Indeed, they are constantly evolving as the project itself evolves. Steps toward these inchoate principles are shown in table 9.7.

The first thing to note about the principles is that their development was influenced not just by psychology, and not just by a consideration of in-school learning. We have been strongly influenced by pertinent branches of linguistics, sociology, and anthropology, and by studies of out of school learning, such as after school, voluntary activities (Heath 1991; Heath and McLaughlin, in press; Laboratory of Comparative Human Cognition 1983), apprenticeships and on the job training (Becker 1972; Lave and Wenger 1991), and studies of communities of professional scientists (Latour 1987; Latour and Woolgar 1986); Medawar 1982; Starr 1983).

Strategies and Metacognition

The first two principles, however, not only show a clear influence of psychological theory, but they have guided our work since its inception. We have an enduring interest in the active, strategic nature of learning (Brown 1974, 1975) and metacognition (Brown 1975, 1978; Brown, Brandford, Ferrara, and Campione 1983; Campione and Brown

Table 9.7
Steps toward first principles of learning

- Active, strategic nature of learning
- Metacognition
  - Awareness and understanding
  - Intentional learning, self-selection, and direction
  - Self-monitoring and other-monitoring for common good
  - Reflective practice
- Multiple zones of proximal development
  - Multiple expertise, multiple roles, multiple resources
  - Mutual appropriation
  - Guided practice, guided participation
- Dialogic base
  - Shared discourse, common knowledge
  - Negotiated meaning and defining
  - Seeding, migration, and appropriation of ideas
- Legitimization of differences
  - Diversity, identity, and respect
  - Creation of community and individual identity
  - Multiple access, multiple ways in
  - Peripheral to full participation
- Community of practice
  - Communities of practice with multiple overlapping roles
  - Sense of community with shared values
  - Volunteers establish curriculum
  - Elements of ownership and choice
  - Community beyond the classroom wall
- Contextualized and situated
  - Purpose for activity, nothing without a purpose
  - Theory and practice in action
  - Repeatable participant structures
  - Fantasy and sociodramatic play (being a researcher, being a teacher)
  - Link between current practice and expert practice transparent
  - Intellectually honest curriculum
  - Responsive, transparent assessment

1978; Campione, Brown, and Ferrara 1982). We will not trace that history here.

Multiple Zones of Proximal Development
The third principle reflects our long-standing interest in American versions of Vygotsky's (1978) theorizing, notably the notion of a zone of proximal development. A zone of proximal development is the region of activity that learners can navigate with aid from a supporting

context, including but not limited to people. In our classroom, teachers and students create multiple zones of proximal development by seeding the environment with ideas and concepts. Participants in the classroom are free to appropriate vocabulary, ideas, methods, and so on that appear initially as part of the shared discourse, and by appropriation, transform these ideas into personal knowledge. Because expertise in the classroom is distributed by design and happenstance (Brown 1992; Brown et al., in press) the seeding and appropriation processes are essentially bidirectional. Everyone is expert in something: nobody, not even the classroom teacher, knows it all.

Dialogic Base
Our classrooms are intentionally designed to give place to multiple voices in Bakhtin's (Holquist and Emerson 1981) sense of *voice* as the speaking personality and the speaking consciousness. A major tenet of Bakhtin's (1986) creed was that "any true understanding is dialogic in nature."

In our classrooms there is the assumption of shared discourse and common knowledge (Edwards and Mercer 1987) as well as individual expertise. The core participant structures of our classrooms are essentially dialogic. Sometimes these activities are face-to-face in small- or large-group interactions; sometimes they are mediated via print or electronic mail; and at still other times they go underground and become part of the thought processes of the community members (Vygotsky 1978). Dialogues provide the format for novices to adopt the discourse structure, goals, values, and belief systems of scientific practice. Over time, the community of learners adopts a common voice and common knowledge base, a shared system of meaning, beliefs, and activity that is as often implicit as it is explicit.

Distributed Expertise. Central to these learning activities is the display of distributed expertise. Ideas and concepts migrate throughout the community via mutual appropriation and negotiation. Some ideas and ways of knowing become part of common knowledge. Other forms of knowledge and knowing remain the special reserve of those who choose to major in a particular form of expertise. The classroom is designed to foster zones of proximal development that are continually the subject of negotiation and renegotiation among its citizens. Through their participation in increasingly more mature forums of scholarly research, students are enculturated into the community practice of scholars. These classrooms encourage the development of a community of discourse pervaded by knowledge-seeking and inquiry processes. Expertise of one form or another is spread throughout and beyond the classroom, and this emergent expertise influences the discourse that provides the seeding ground for the mutual negotiation and appropriation activities of its members. The metaphor of a classroom supporting multiple, overlapping zones of proximal development that foster growth through mutual appropriation and negotiated meaning is the theoretical window through which we view the system of classroom activity and the community practices that arise within it.

Legitimization of Differences in a Community of Scholastic Practice

Differences are rarely tolerated in traditional schools. The common practice is for students to be arranged by age and subjected to "age-appropriate" segregated curricula. This common contemporary practice, not part of the one-room schoolhouse, is based on the assumption that students of the same age can do the same amount of work, or grasp a certain amount of material, at the same time.

Not surprisingly, given the tradition of twentieth-century schooling, the notion of legitimization of differences comes from out of school learning. Heath (1991) regards this principle as essential for understanding such activities as volunteer, after-school programs, notably little league baseball. Central features of Little League participation, for example, are that all participants are volunteers (coaches, kids, parents, back benchers, etc.); that they come in all shapes, sizes, and abilities; that the coach is many more things than a teacher; and that there is more than one coach. The role of the coach is central, but so is this distributed expertise:

> Central to the task of coaching many learners at the same time is acceptance of the value of differences among learners. A team cannot expect to have all members at the same level of ability in the same complex skills. Instead, the potential for division of labor depends on varying levels of performance in each niche; however, the general upgrading of performance for each individual rests in the social control potential of having knowledge about separate tasks shared and distributed among all members. Added to the general distributions of knowledge is the shared value of monitoring self and others . . . , which result in group improvement through individual achievement. (Heath 1991, 121)

Heath and McLaughlin (in press) describe several features of successful youth activities that inner-city youth volunteer to join. We try to mimic some aspects of these successful organizations in our restructuring of schools. In addition to the respect and legitimization of diversity, experience, and talent, we believe that the sense of imagined family, where older and more experienced participants guide new members is important. Seasonal cycles of planning, preparing, practicing, and performing to outside audiences, with real deadlines that provide points for self-reflection and taking stock, also provide the backbone of these organizations. An atmosphere of mutual monitoring and support, with assigned responsibility for group progress, makes these organizations safe havens for youth, havens they rarely experience in school.

To the extent we are able, we aim to mimic this philosophy within classrooms. We try to create a community of scholastic practice within which expertise is distributed (Brown et al., in press): everyone is a researcher, everyone is a teacher, everyone is a writer, everyone is an expert at something. Everyone is involved in a plan-prepare-practice-perform cycle with tangible results. Identities are created, and a sense of community with shared values emerges. Students say that they feel ownership, and although it can't be absolute, there is a sense of volunteerism and choice in these classrooms. There are multiple ways to full participation, and peripheral participation in some aspects of the work is legitimized (Campione, Rutherford, Gordon, Walker, and Brown, in press; Lave and Wenger 1991).

Respect. Coupled with responsibility and the acceptance of legitimate differences comes respect, respect between students, between students and school staff, and between all members of the extended community, including experts available by electronic mail. Students' questions are taken seriously. Experts, be they children or adults, do not always know the answers: known-answer question-and-answering games (Heath 1983; Mehan 1979) have no home in this environment. Respect is earned by responsible participation in a genuine knowledge-building community (Scardamalia and Bereiter 1991).

One main goal of the project is to distill critical features of successful after-school activities and work (often subversively) to restructure school practices so that this type of learning environment can support academic work of some authenticity and integrity.

Contextualized and Situated

Wherever possible, we situate academic activities such that the goals of the enterprise are apparent to the participants. This is not an easy task, as academic "work" is notorious for its disassociated, inauthentic nature (see Scardamalia, Bereiter, and Lamon, chapter 8 of this volume). There is often a dramatic lack of continuity between school activities and the cultures of both childhood and legitimate adult occupations (Cole and Bruner 1971). We attempt to forge a link between school activity and outside activities. Even as young as seven, students engage in sociodramatic play (Heath 1991) when they practice being a researcher, being a teacher, being a scientist, and so forth.

Because we are not running a Little League team, and are partially responsible for the education of a large number of students, we must be responsive to the agreed-upon guidelines of what it is that students should learn. We attempt to provide what Bruner referred to as an "intellectually honest curriculum," one that is tailored to a child's age and interests, but with fidelity to the content area in question. Similarly, we have attempted to provide transparent assessment and other self-assessment procedures (Frederiksen and Collins 1989) so that the name of the game is clear to all. Enlisting students as designers and evaluators of their own learning is one of the most important activities of the Community of Learners. The philosophy behind this emphasis is an outcome of our long-standing interest in metacognition. It is a fundamental tenet of our theory that students have a right to understand, evaluate, and orchestrate their own learning.

Notes

This research was supported by grants from the James S. McDonnell and Andrew W. Mellon Foundations, and from the Evelyn Lois Corey Research Fund to Ann L. Brown.

An inner-city grade school in Oakland, California, has for three years been the primary host to our program. Thanks are due to the teachers and students for their unfailing help and support. The authors thank Principal Sallyann Tomlin for her gracious encouragement. Special thanks are due to second grade teacher Jill Walker and sixth grade teacher Stella Kennedy, who have worked with us most intensively. Thanks are also due to the many colleagues who have worked on this project, most notably Doris Ash, Kathy Nakagawa, and Marty Rutherford. And of course we could not operate without the support of the children, whose patience, humor, and eagerness to learn are a constant delight.

1. The work of the project takes place in inner-city schools serving a diverse population of students at risk. The majority of students are African-Americans (approximately 65%), with the remaining students consisting of Asian (15%), Pacific Islanders (6%), Hispanic (2%), and Caucasian (12%). Many children are mainstreamed; the majority are from single-parent or grandparent homes, and approximately half are recipients of Aid to Families with Dependent Children.

CONCLUSION