

# Classroom Lessons: Integrating Cognitive Theory and Classroom Practice

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edited by Kate McGilly

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## Chapter 9

### Guided Discovery in a Community of Learners

*Ann L. Brown and Joseph C. Campione*

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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 untrammelled 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 "literate 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, questioning, 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<sup>1</sup>, 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 rela-

tionships 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).

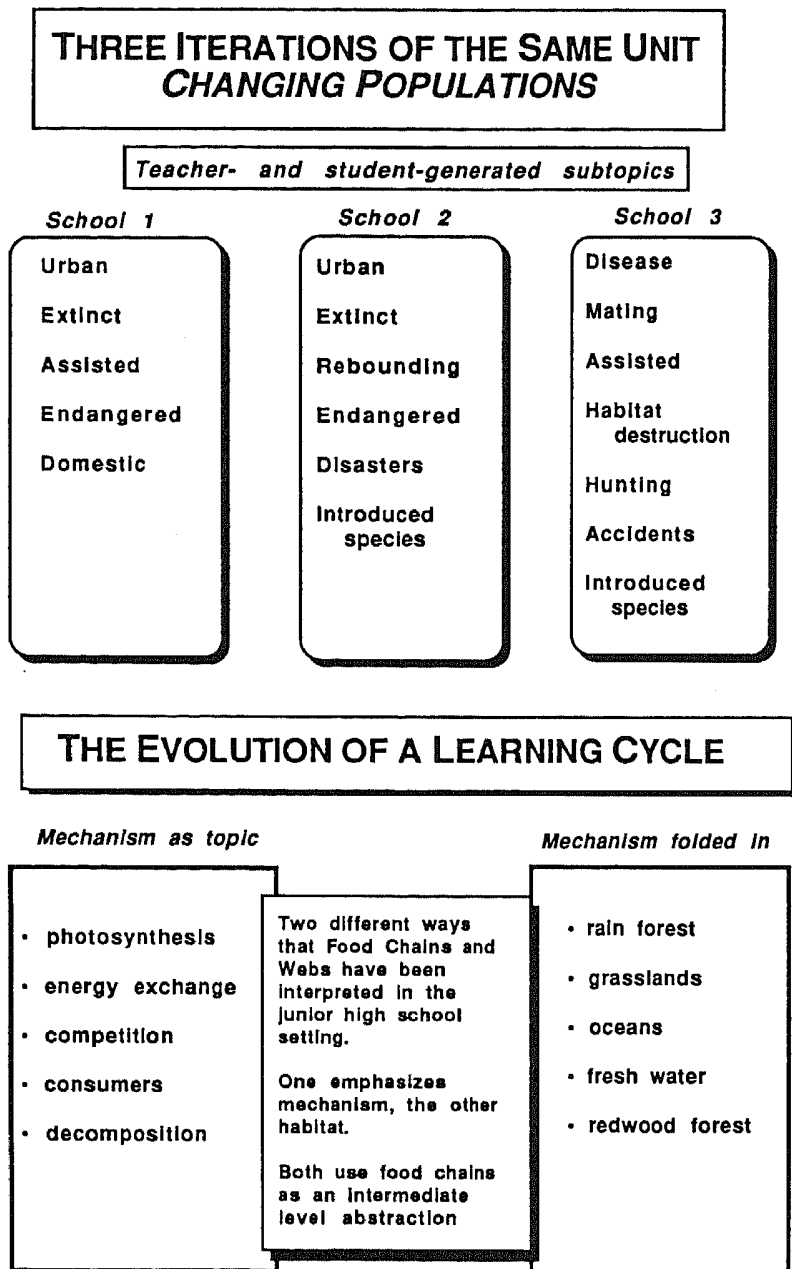
Mutual appropriation refers to the bidirectional nature of the appropriation process, one that should not be viewed as limited to the process by which the child (novice) learns from the adult (expert) via a static process of imitation, internalizing observed behaviors in an untransformed manner. Rather, 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



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.

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

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 arthropods, 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 breast 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

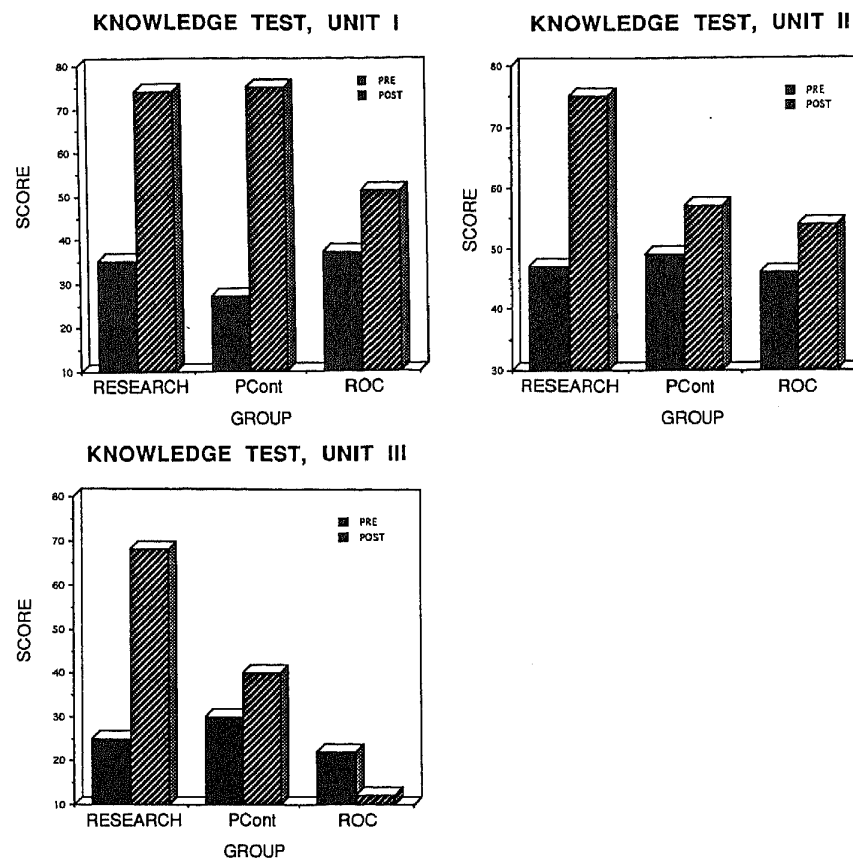


Figure 9.2  
Results of unit content knowledge tests in a fifth and sixth grade full-year intervention. PCont = partial control group, who were students in the first semester (unit 1), then taught by their regular classroom teacher. ROC = a read-only control group that read the key materials but did 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?**

<u>First interview</u>	<u>Six months later</u>
<p>S: . . . well I mean if people can, like, are vegetarians, I mean I think a cheetah could change . . .</p> <p>When asked how this might happen:</p> <p>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.</p> <p>When asked if it would be easier for a baby cheetah to eat grass:</p> <p>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 . . .</p>	<p>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.</p> <p>When asked if the baby cheetah could survive by eating grass, the student asserted that they would probably be the first to die.</p> <p>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:</p> <p>S: Nice try . . . the digestive track of the deer is too complicated and also the teeth wouldn't be able to grind meat.</p>

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

**Use of Biological Principles: Habitat Task  
Design an Animal Version (6th Grade)**

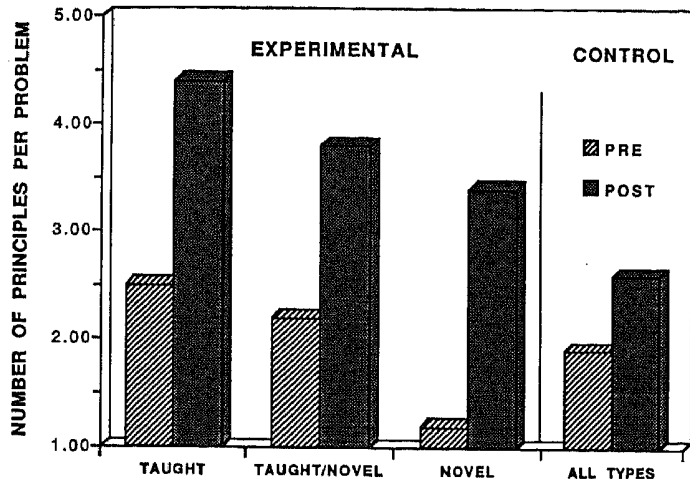


Figure 9.4 Pre- and posttest scores on a transfer test: Design an animal to fit a habitat

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 (White head 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

**Comprehension Measures**

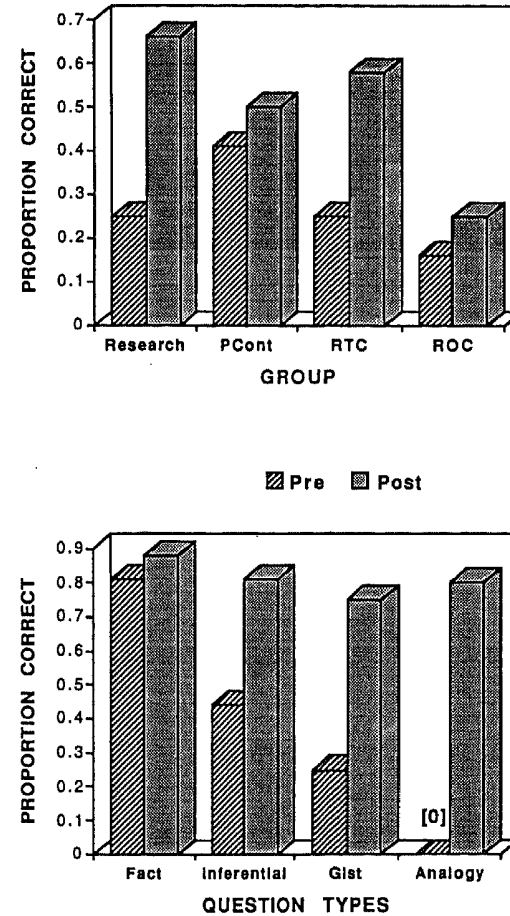


Figure 9.5 Reading comprehension measure in domain outside biology. PCont = partial control group as in figure 9.2. RTC = a reciprocal teaching control group. ROC = read-only control.

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