Learning in doing: Social, cognitive, and computational perspectives

GENERAL EDITORS: ROY PEA
JOHN SEELY BROWN

The construction zone: Working for cognitive change in school
Denis Newman, Peg Griffin, and Michael Cole

Plans and situated actions: The problem of human–machine interaction
Lucy Suchman

Situated learning: Legitimate peripheral participation
Jean Lave and Etienne Wenger

Street mathematics and school mathematics
Terezinha Nunes, Analucia Dias Schliemann, and David William Carraher

Understanding practice: Perspectives on activity and context
Seth Chaiklin and Jean Lave (editors)

Distributed cognitions

Psychological and educational considerations

Edited by
GAVRIEL SALOMON
University of Haifa, Israel

CAMBRIDGE
UNIVERSITY PRESS

7 Distributed expertise in the classroom

Ann L. Brown, Doris Ash, Martha Rutherford, Kathryn Nakagawa, Ann Gordon, and Joseph C. Campione

It is commonly agreed that we are currently witnessing a resurgence of interest in situated cognition, for want of a better name (for a brief history, see Cole & Engeström, Chapter 1, this volume). A main tenet of this philosophy is that knowledge does not consist of static "furniture of the mind" (Hall, 1881); knowledge is situated in activity. Railing against the prevailing cognitive position that knowledge consists of representations in the mind, Lave (1988) further argues:

> The point is not so much that arrangements of knowledge in the head correspond in a complicated way to the world outside the head, but that they are socially organized in such a fashion as to be indivisible. "Cognition" observed in everyday practice is distributed – stretched over, not divided among – mind, body, activity and culturally organized settings (which include other actors). (p. 1)

Ways of knowing are deeply connected to the cultural artifacts of situations, artifacts that include tools and people. In this chapter we will indicate how an appreciation of the distributed nature of expertise influences, and is played out, in the design of our classrooms. To do so, we will give examples of distributed cognition in classrooms among students, teachers, computer tools, and other artifacts that frame their thinking (see also Brown, 1992).

In its new clothes, the concept of situated learning rests heavily on the notion of communities of practice (Bordieu, 1972). Lave and

The research reported in this chapter was supported by grants from the James S. McDonnell and Andrew W. Mellon Foundations, and by Evelyn Lois Corey research funds to the first three authors.

Wenger (1991) argue that participation in practice is the main activity through which learning occurs:

> Conceiving of learning in terms of participation focuses attention on ways in which it is an evolving, continuously renewed set of relations. . . . Participation . . . can be neither fully internalized as knowledge structures nor fully externalized as instrumental artifacts or overarching activity structures. Participation is always based on situated negotiation and renegotiation of meaning in the world. This implies that understanding and experience are in constant interaction – indeed, are mutually constitutive. (pp. 49–52)

In this chapter we will examine grade school science classes as a community of practice, although J. S. Brown, Collins, and Duguid (1989) argue that this is just what schools typically are not. They argue that the professions, trades, and academic disciplines create cultures of practitioners into which novices are inducted during a long period of apprenticeship. Enculturation is time-consuming because it involves adopting the ways of knowing, cultural practices, discourse patterns, and belief systems of the discipline or trade in question.

J. S. Brown et al. (1989) make a distinction between authentic activity, somewhat loosely defined as the activity of actual practitioners of a craft, and the contrast class – schoolwork – that is to a large part inauthentic. This point was made some years ago by Cole and Bruner (1971), who pointed out the lack of continuity between school activities and both the cultures of childhood and legitimate adult occupations, as of course did Dewey (1902). In this chapter we will discuss what makes common school activities inauthentic and outline just what we feel *would* constitute authentic activity in, say, grade school.

It is clearly romantic to suggest, as do J. S. Brown et al., that students in public schools be enculturated into the cultures of mathematicians, historians, and literary critics. For a start, practitioners of these callings do not as a rule populate schools; teachers of these subjects may be consumers of the outputs of these disciplines, but they are rarely practitioners. History teachers are seldom historians. Practicing mathematicians infrequently teach high school, let alone grade school.

If it is not to apprentice children to the traditional academic disciplines, what is the purpose of schooling? Schools evolved to encourage a form of universal literacy that would enable graduates to be informed consumers, interpreters, and critics of science, history, economics, and literature. As Wineburg (1989) points out, the popularity of Stephen Jay Gould to millions of paleontologically untutored readers and of Barbara Tuchman to history buffs demonstrates that, to a certain degree, biology and history can be enjoyed by educated nonspecialists. He argues that "to write history (to be a historian) people may need to adopt the belief systems of historians and be conversant with their culture. But writing history and learning to appreciate it are different things." Even without an appreciation for daily life in grade school, the armchair philosopher must see the impracticality of suggesting that children be enculturated into the society of historians, biologists, mathematicians, and literary critics. This may be the desired state of first-rate graduate school education, but it is surely not a reasonable expectation for grade school. And while the point is well taken that many classroom rituals are divorced from the activities of scholars and professionals and even the spontaneous learning of childhood (Gardner, 1991), the question remains, What should constitute authentic activity in the classroom?

We argue that schools should be communities where students learn to learn. In this setting teachers should be models of intentional learning and self-motivated scholarship, both individual and collaborative (Brown, 1992; Brown & Campione, 1990; Scardamalia & Bereiter, 1991). If successful, graduates of such communities would be prepared as lifelong learners who have learned how to learn in many domains. We aim to produce a breed of "intelligent novices" (Brown, Bransford, Ferrara, & Campione, 1983), students who, although they may not possess the background knowledge needed in a new field, know how to go about gaining that knowledge. These learning experts would be better prepared to be inducted into the practitioner culture of their choosing; they would also have the background to select among several alternative practitioner cultures, rather than being tied to the one to which they were initially indentured, as in the case of traditional apprenticeships.

Ideally, in a community of learners, teachers and students serve as role models not only as "owners" of some aspects of domain knowledge, but also as acquirers, users, and extenders of knowledge in the sustained, ongoing process of understanding. Ideally, children are *apprentice learners,* learning how to think and reason in a variety of domains. By participating in the practices of scholarly research, they should be enculturated into the community of scholars during their 12 or more years of apprenticeship in school settings. Redesigning classrooms so that they can bolster this function is a primary aim of our research group (Brown, 1992). In our classroom interventions we try to create a community of discourse (Fish, 1980) where the participants are inducted into the rituals of academic and, more particularly, scientific discourse and activity (Brown & Campione, 1990, in press; Lempke, 1990; Michaels & O'Connor, in press).

In this chapter we will concentrate on how expertise is spread throughout the classroom and how such distributed expertise influences the community of discourse that provides the seeding ground for mutual appropriation. We begin with a discussion of the central theoretical concepts that guide our work and then proceed with a practical discussion of how to engineer communities of learning. We then discuss the roles of participants in the community (Brown & Campione, 1990, in press) and conclude with a discussion of what authentic school activity might be.

Mutual appropriation and negotiation in a zone of proximal development

Theoretically, we conceive of the classroom as composed of zones of proximal development (Vygotsky, 1978) through which participants can navigate via different routes and at different rates (Brown & Reeve, 1987). A zone of proximal development can include people, adults and children, with various degrees of expertise, but it can also include artifacts such as books, videos, wall displays, scientific equipment, and a computer environment intended to support intentional learning (Campione, Brown, & Jay, 1992; Scardamalia & Bereiter, 1991). 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 (Vygotsky, 1978). It defines the distance between current levels of comprehension and levels that can be accomplished in collaboration with people or powerful artifacts. The zone of proximal development embodies a concept of readiness to learn that emphasizes upper levels of competence. Furthermore, these upper boundaries are seen not as immutable but as constantly changing with the learner's increasing independent competence at successive levels.

In our classroom, researchers and teachers deliberately create zones of proximal development by seeding the environment with ideas and concepts that they value and by harvesting those that "take" in the community. But so too do the children. 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 via personal interpretation. Ideas that are part of the common discourse are not necessarily appropriated by all, or in the same manner by those who do. Because the appropriation of ideas and activities is multidirectional, we use the term "mutual appropriation" (Moschkovich, 1989; Newman, Griffin, & Cole, 1989; Schoenfeld, Smith, & Arcavi, in press).

It is useful to address the difference between the terms "internalization" and "appropriation," used to express the essential learning mechanism in Vygotskian theory. Rogoff (1990) uses the term "appropriation" as a substitute for "internalization" within a Vygotskian model of learning because internalization implies that individuals are separate from one another and learn by observing and then taking within themselves the results of that observation. The term "appropriation" is readily being used in place of "internalization" because of the widespread belief that use of the term "internalization" (1) merely renames a learning mechanism that is not understood and (2) implies that the fruits of learning, although initially gained in social interaction, somehow come to reside in individual minds.

The first question – whether the use of the term "internalization" really gets us farther along in addressing the time-honored problem of the actual mechanism of learning, that is, the Hoffding step (1892) – is addressed by Bereiter (1985) in his article on problematic learning and Fodor's (1980) learning paradox:

> Following Vygotsky, . . . one might formulate the following explanation: Learning does indeed depend on the prior existence of more complex structures, but these more complex cognitive structures are situated in the culture, not the child. . . . Through . . . shared activities the child internalizes the cognitive structures needed to carry on independently. Such an explanation, satisfying as it may appear, does not eliminate the learning paradox at all. The whole paradox hides in the word "internalizes." How does internalization take place? (p. 206)

To Rogoff (1990) and Newman et al. (1989), the concept of appropriation is seen as the answer to a prayer, in that they believe it solves the problem of Fodor's (1980) paradox and Bereiter's (1985) concept of problematic learning. Fodor also criticized Vygotsky's theory for not telling us where hypotheses come from, that is, for not unpacking the essential learning mechanism. We believe this critical question still remains unanswered, even with the change in terms (but see Newman et al., 1989).

The second, and more compelling, reason for switching to the term "appropriation" is that it is theoretically neutral with respect to the location of knowledge for those allergic to the notion of having anything inside the head. And theoretical disputes notwithstanding, we have found the concept of mutual appropriation operating within a zone of proximal development (ZPD) to have practical implications for how classrooms are orchestrated and observed. In their discussion of appropriation, Newman et al. (1989) emphasize that it is a two-way process:

> . . . the teacher reciprocally applies the process of appropriation in the instructional interactions. In constructing a ZPD for a particular task, the teacher incorporates children's actions into her own system of activity.
>
> *Just as the children do not have to know the full cultural analysis of a tool to begin using it, the teacher does not have to have a complete analysis of the children's understanding of the situation to start using their actions in the larger system.* The children's actions can function within two different understandings of the significance of the task: the child's and the teacher's. Both are constrained by sociohistorical understandings of the activity setting in which they are interacting. The fact that any action can always have more than one analysis makes cognitive change possible. Children can participate in an activity that is more complex than they can understand, producing "performance before competence," to use Cazden's (1981) phrase. While in the ZPD of the activity, the children's actions get interpreted within the system being constructed with the teacher. Thus the child is exposed to the teacher's understanding without necessarily being directly taught. (pp. 63–4)

The term "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 third central concept that guides our thinking is that of mutual negotiation. Via emergent discourse genres and activity structures, meaning is constantly negotiated and renegotiated by members of the community. 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 proof themselves are open to renegotiation in multiple ways (Bloor, 1991) as the elements that compose them, such as terms and definitions (O'Connor, 1991), are renegotiated continuously. Successful enculturation into the community leads participants to relinquish everyday versions of speech activities having to do with the physical and natural world and replace them with "discipline embedded special versions of the same activities" (O'Connor, 1991).

The core participant structures of our classrooms are essentially dialogic. Sometimes these activities are undertaken 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 individual members of the community (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 (Edwards & Mercer, 1987), a shared system of meaning, beliefs, and activity that is as often implicit as it is explicit.

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. In the next section we will turn to the practical, and describe how we attempt to engineer daily activity so that classrooms can be transformed into learning communities.

Engineering a community of learners

Over the past five years, we have been engaged in several attempts to design innovative classroom practices that would encourage students, teachers, and researchers to rethink the philosophy of learning that underlies their practices. In this section, we first delineate the basic classroom activity structures, then describe how we foster the classroom ethos that would permit intentional learning and distributed expertise. We discuss data from a variety of repetitions of our design experiments (Brown, 1992; Collins, in press), but in general the students are fifth- through seventh-graders from inner-city schools. In one representative sixth-grade class, 60% of the students were African Americans, 15% Asian, 12% Caucasian, 6% Pacific Islanders, and 7% other. Forty-two percent of the families of these children were recipients of Aid to Families with Dependent Children. The majority of the children can be described as academically at risk on the basis of standardized scores that paint an unduly pessimistic picture of their capabilities. It is important to note that the children in this classroom were emergent language learners in many ways. In addition to the fact that 87% were bilingual or bidialectical, all were being introduced to the discourse of science for the first time (Ochs, 1991; Rutherford, 1991).

Main features of the classroom

Collaborative learning. Two forms of collaborative learning serve as repetitive structures in the classroom: reciprocal teaching (Palincsar & Brown, 1984) and the jigsaw method (Aronson, 1978).

Reciprocal teaching is a method of enhancing reading comprehension modeled after studies of Socratic or Inquiry teaching and theories about plausible reasoning, explanation, and analogy (Brown & Palincsar, 1989; Collins & Stevens, 1982). The procedure was designed to encourage the externalization of simple comprehension-monitoring activities and to provide a repetitive structure to bolster student discourse. An adult teacher and a group of students take turns leading a discussion, the leader beginning by *asking a question* and ending by *summarizing* the gist of what has been read. The group rereads and discusses possible problems of interpretation when necessary. Questioning provides the impetus for discussion. Summarizing at the end of a period of discussion helps students establish where they are in preparation for tackling a new segment of text. Attempts to *clarify* any comprehension problems that might arise occur opportunistically, and the leaders asks for *predictions* about future content. These four activities – questioning, clarifying, summarizing, and predicting – were selected to bolster the discussion because they are excellent comprehension-monitoring devices; for example, an inability to summarize what has been read indicates that understanding is not proceeding smoothly and remedial action is called for. The strategies also provide the repeatable structure necessary to get a discussion going, a structure that can be gradually eliminated when students are experienced in the discourse mode (Brown & Palincsar, 1989).

In the context of these reciprocal reading groups, students with various levels of skill and expertise can participate to the extent that they are able and benefit from the variety of expertise displayed by other members of the group. Reciprocal teaching was deliberately designed to evoke zones of proximal development within which novices could take on increasing responsibility for more expert roles. The group cooperation ensures mature performance, even if individual members of the group are not yet capable of full participation.

An important point about reciprocal teaching is that the authenticity of the target task (text comprehension) is maintained throughout; components are handled in the context of an authentic task, reading for meaning; skills are practiced in context. The aim of understanding the texts remains as undisturbed as possible, and the novice's role is made easier by the provision of expert scaffolding and a supportive social context that does a great deal of the cognitive work until the novice can take over more and more of the responsibility. The task, however, remains the same, the goal the same, the desired outcome the same. There is little room for confusion about the point of the activity. As we have argued before:

> The cooperative feature of the learning group in reciprocal teaching, where everyone is trying to arrive at consensus concerning meaning, relevance, and importance, is an ideal setting for novices to practice their emergent skills. All the responsibility for comprehending does not lie on their shoulders, only part of the work is theirs, and even if they falter when called on to be discussion leaders, the others, including the adult teacher, are there to keep the discussion going. The group shares the responsibility for thinking and thus reduces the anxiety associated with keeping the argument going singlehandedly. Because the group's efforts are externalized in the form of a discussion, novices can contribute what they are able and learn from the contributions of those more expert than they. It is in this sense, the reciprocal teaching dialogues create a zone of proximal development for their participants, each of whom may share in the activity to the extent that he or she is able. Collaboratively, the group, with its variety of expertise, engagement, and goals, gets the job done; the text gets read and understood. (Brown & Palincsar, 1989, p. 415)

The *jigsaw method* of cooperative learning was adapted from Aronson (1978). Students are assigned part of a classroom topic to learn and subsequently to teach to others via reciprocal teaching. In our extrapolation of this method, the setting is an intact science classroom where students are responsible for doing collaborative research and sharing their expertise with their colleagues. In effect, the students are partially responsible for designing their own curriculum. Students are assigned curriculum themes (e.g., animal defense mechanisms, changing populations, food chains), each divided into five subtopics (e.g., for changing populations: extinct, endangered, artificial, assisted, and urbanized; for food chains: producing, consuming, recycling, distributing, and energy exchange). Students form five *research groups,* each assigned responsibility for one of the five subtopics. The research groups prepare teaching materials using state-of-the-art but inexpensive computer technology (Campione et al., 1992). Then, using the jigsaw method, the students regroup into *learning groups* in which each student is the expert in one subtopic, holding one-fifth of the information. Each fifth is combined with the remaining fifths to make a whole unit, hence "jigsaw." The expert on each subtopic is responsible for guiding reciprocal teaching learning seminars in his or her area. Thus, the choice of a learning leader is now based on expertise rather than random selection, as was the case in the original reciprocal teaching work. All children in a learning group are experts on one part of the material, teach it to others, and prepare questions for the test that all will take on the complete unit.

The research cycle. In a typical research cycle, lasting approximately 10 weeks, the classroom teacher or a visiting expert introduces a unit with a whole class discussion, a benchmark lesson (Minstrell, 1989) in which she elicits what the students already know about the topic and what they would like to find out. She also stresses the "big picture," the underlying theme of that unit and how the interrelated subtopics form a jigsaw; the complete story can be told only if each research group plays its part. Subsequent benchmark lessons are held opportunistically to stress the main theme and interconnectedness of the activities and to lead the students to higher levels of thinking. The students see that their studies are connected to larger global issues. Gradually, distributed expertise in the various groups of students is recognized. Students turn to a particular group for clarification of information that is seen to be within their domain. Faced with questions and information from nonexperts, the research teams upgrade, revise, and refine their research agendas.

The majority of time is spent in the research-and-teach part of the cycle. Here the students generate questions, a process that is under continual revision. They plan their research activities and gather information using books, videos, and their own field notes, all with the help of Browser (Campione et al., 1992), an electronic card catalog, developed for use on the Macintosh system, that enables children to find materials via cross-classification (e.g., "Find me all examples of insect mimicry in the rain forest"). Students also have access, via electronic mail, to experts in a wider community of learners, including biologists, computer experts, and staff at zoos, museums, and other sources.

At intervals during the research cycle, students break up into reciprocal teaching sessions to attempt to teach their evolving material to their peers. Fueled by questions from their peers that they cannot answer, they redirect their research and undertake revisions of a booklet covering their part of the information. Reciprocal teaching sessions are also scheduled opportunistically by the students themselves when a research group decides that a particular article is crucial for their argument and is difficult to understand. Reciprocal teaching thus becomes a form of self-initiated comprehension monitoring.

At the end of the unit, the students conduct full reciprocal teaching sessions in groups composed such that each child is an expert on one-fifth of the material. They teach their material to one another. Finally, the students as a whole class conduct a quiz game in preparation for a test covering all sections of the material. This test is composed of questions made up by the research teams on their material, supplemented by items generated by the teacher. A whole-class debriefing session follows the test, where students discuss not only "right" versus "wrong" answers but whether or not the questions were important, meaningful, or just plain fair. After this experience, the students revise their booklets and combine them into a single whole-class book on the entire unit, consisting of the five separate sections of the five research teams together with an overall introduction and discussion concentrating on the common theme and big picture to which all subunits contributed. This research cycle is then repeated with the next unit.

The ethos of the classroom. In order for these classrooms to be successful, it is imperative that a certain ethos be established early and maintained throughout. How this is done is difficult to describe and equally difficult to transmit to novice teachers except through demonstration, modeling, and guided feedback. Expert teachers claim to recognize "it" when they see it. But what is it?

We believe that the classroom climate that can foster a community of learners harbors four main qualities. First is an atmosphere of 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 group uncovers and delineates aspects of knowledge "possessed" by no one individual. The atmosphere of joint responsibility is critical for this enterprise.

Coupled with joint responsibility comes respect, respect among students, between students and school staff, and among all members of the extended community that includes experts available by electronic mail (as described later). 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 & Bereiter, 1991). When an atmosphere of respect and responsibility is operating in the classroom, it is manifested in several ways. One excellent example is turn taking. Compared with many excerpts of classroom dialogue, we see relatively little overlapping discourse. Students listen to one another.

Concomitant with this development is the emergence of children who become experts in social facilitation and dispute reconciliation. Consider this diplomatic statement from a student who, at the beginning of the intervention, was notorious for his arrogance and inability to admit to being wrong – or to listen:

> At first I thought I agreed with S [that pandas are fat because they are indolent], except it really takes a lot of exertion to climb trees. It does. They must burn their energy climbing because remember we saw them in that laser disc . . . how the panda was climbing trees to get to the bamboo.
>
> I'm sort of getting two pictures. First you're saying there's plenty of bamboo, and they sit around and munch it all day and then you say that their bamboo is dying off. Can you sort of set me straight?

This brings us to the third critical aspect of the classroom: A community of discourse (Fish, 1980) is established early in which constructive discussion, questioning, and criticism are the mode rather than the exception. Meaning is negotiated and renegotiated as members of the community develop and share expertise. The group comes to construct new understandings, developing a common mind and common voice (Wertsch, 1991).

The final aspect of these classrooms is that of ritual. Participation frameworks (Goodwin, 1987) are few and are practiced repeatedly so that students, and indeed observers, can tell immediately what format the class is operating under at any one period of time. One common way of organizing the classroom is to divide the students into three groups, those composing on computers, those conducting research via a variety of media, and those interacting with the classroom teacher in some way: editing manuscripts, discussing progress, or receiving some other form of teacher attention. Another repetitive frame is one in which the class is engaged in reciprocal teaching or jigsaw group activities, with approximately five research/learning groups in simultaneous sessions. Still another activity is one in which the classroom teacher or an outside expert conducts a benchmark lesson, introducing new items, stressing higher-order relationships, or encouraging the students 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 & Schultz, 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 discovery in these classrooms, they are highly structured to permit students and teachers to navigate between repetitive activities with as little effort as possible.

Distributed expertise

In order to foster and capitalize on distributed expertise, certain classroom rituals are deliberately engineered for that effect while other opportunities arise serendipitously. As described before, the two major forms of collaborative learning, jigsaw and reciprocal teaching, are designed so that students will teach from strength. In addition to the two main teaching/learning activity structures, expertise is intentionally distributed through the practice of instructing only a few children in some aspect of knowledge – for example, when novel computer applications are introduced. Only one group receives instruction in the use of, say, a scanner that will enable them to copy pictures and text, including their own compositions, directly into their documents. It is the responsibility of each designated group to tutor all other students in the class in the use of a particular application. Students who have this responsibility behave differently from those who do not, repeating what the teacher says and attempting to perform each step before proceeding, a form of self-monitoring. It may take several repetitions of this selective teaching for students to take their responsibility seriously. They must realize that unless the scanner students share their newfound knowledge, members of their class will be denied expertise in the use of this tool. But by the same token, the scanner students are dependent on those who have privileged access to, say, MacDraw, in order to learn that application. In this way, an atmosphere of mutual dependency and trust is built up, with students recognizing shared responsibility for knowledge dissemination.

Expertise is distributed by design, but in addition variability in expertise arises naturally within these classrooms. 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; some adopt a particular endangered species (pandas, otters, and whales being popular). Others become animal "trivial-pursuit" experts, amassing a body of knowledge about rare and unusual animals. Still others become environmental activists, collecting instances of outrages from magazines, television, and even newspapers, and demanding that the class write to Congress and complain. And still others become experts in graphics and desktop publishing and other aspects of the technology; for although all students are inducted into the basics of the computer environment, progression to the use of increasingly complex software is a matter of choice. Within the community of the classroom, these varieties of expertise are implicitly recognized, although not the subject of much talk. As the children are free to ask help of the adults or one another, help-seeking behavior reveals who is seen to own what "skills," what "piece" of the knowledge, and so on. Subcultures of expertise develop: who knows about Cricket or Powerpoint; who can help you back up files; who knows everything there is to know about the *Valdez* oil spill; and so on.

Another interesting phenomenon is the process by which this knowledge is disseminated. For example, consider the computer mavens. In one study, in order to whet the children's interest, we added software without telling them. A minority of the children enjoyed this game, eager to find out what the new icon in their desktop was. When they had learned how to use it (with expert help), they spread this information to a subset of other computer majors and to no one else. The members of this subcommunity were clearly recognized by both in-group members and the community at large, as witnessed by the depth of knowledge dissemination within the group and the pattern of help-seeking behavior by noncognoscenti.

Recognition of expertise was also reflected in the roles students assumed in the discussions. When an expert child made a statement, the class deferred to that child in both verbal and nonverbal ways. Status in the discussion did not reside in the individual child, however, as in the case of established leaders and followers, but was a transient phenomenon that depended on a child's perceived expertise within the domain of discourse. As the domain of discourse changed, so too did the students who received deferential treatment.

Table 7.1. *Changes in classroom philosophy*

Role of	Traditional classroom	Intentional learning environment
Students	Passive recipients of incoming information	Students as researchers, teachers, and monitors of progress
Teachers	Didactic teaching	Guided discovery
	Classroom manager	Model of active inquiry
Content	Basic literacy curriculum, lower vs. higher skills	Thinking as basic literacy
	Content curriculum	Content curriculum
	Breadth	Depth
	Fragmented	Recurrent themes
	Fragmented	Explanatory coherence
	Fact retention	Understanding
Computers	Drill and practice	Tools for intentional reflection
	Programming	Learning and collaboration
Assessment	Fact retention	Knowledge discovery and utilization
	Traditional tests	Performance, projects, portfolio

Traditional classrooms versus communities of learners

The activity patterns in our classrooms contrast in striking ways with those in traditional classrooms. We present a few examples in Table 7.1. These contrasts should be viewed as ends of continua rather than dichotomous; as bald dichotomies they represent stereotypes.

Far from being passive recipients of incoming information, students take on the role of active researchers and teachers, monitoring their own progress and that of others when they adopt the role of constructive critics. Teachers, also, are no longer managers and didactic teachers, but models of active learning and guides to aid the students' learning. The content is intended as a "thinking curriculum" (Resnick, 1987), where depth of understanding and explanatory coherence are valued over breadth of coverage and fact retention. Computers are used as tools for communication and collaboration, but also as aids to reflective learning – students set their own learning goals and monitor their own progress (Brown & Campione, 1990;

Scardamalia & Bereiter, 1991). Finally, tests and assessments are on-line and dynamic, concentrating again on the understanding and use of knowledge rather than fact retention.

In the context of this chapter, it is important to note that the design of our classrooms is itself an excellent example of the influence of distributed expertise. A main tenet of the design experiment is that of a meaningful collaboration between teachers and researchers. We aim at the development of both teacher-researchers and researcher-teachers. Whereas some in our group have devoted the lion's share of their professional activities to theory and research on children's thinking and learning, others have specialized in biology or technology, and still others have been more concerned with the practical orchestration of learning in the classroom. No set of individuals has a complete set of answers, and the multiple and distributed pieces of expertise are equally valued. Discussions involving these groups – as with the discussions among students, between students and adults, and so on – provide a setting for mutual appropriation. The ideas that emerge in the discourse, and their implementation in the classroom, are dictated or owned by no individual group, but are substantially influenced by all. In this process, an instructional program emerges, and all the participants come away with appreciably altered understandings.

In this section, we will amplify this theme and consider five roles within the community of learners that contribute to an atmosphere of distributed expertise: those of the student, teacher, curriculum, technology, and assessment.

The role of students. Students are asked to serve as teachers, editors, advisers, and mentors, making comments on one another's work and entering a network of learners with various degrees of expertise in the domain. In addition, rather than just reading about science, they are asked to do science through hands-on experiments, constructively criticizing the work of others, and seeing their work come to fruition in published forms. Students are encouraged to think of themselves as junior scientists, to the extent possible, rather than functioning only as consumers of others' science.

An essential part of the classroom is establishing a collaborative and cooperative atmosphere. Students are required to collaborate most directly in their research groups, but they also collaborate with other groups and with community members outside the classroom walls. In the course of doing research, students are bound to encounter information that would be helpful to other groups, and we encourage them to communicate those findings, verbally or electronically. Similarly, when students share their long-term projects in jigsaw, they are encouraged to provide feedback to one another, including both constructive criticism and suggestions about additional information sources.

The role of teachers. Although teachers and students view themselves as community members, the adult teacher is clearly first among equals, for she has a clear instructional goal. In many forms of cooperative learning, students are left to construct learning goals for themselves; the goals change over time as interests change, and groups sometimes concoct goals far different from those envisaged by the authorities (Barnes & Todd, 1977). In our classroom, the research direction of the group is not so democratic: The adult teacher's goal is clearly one of keeping the discussion focused on the content and seeing that enough discussion takes place to ensure a reasonable level of understanding.

Teachers are encouraged to hold goals for each research group, with the hope that the students will reach those goals through their own efforts. But if they do not, the teacher will invite the students to arrive at a mature understanding by whatever means she can, including, as a last resort, explicit instruction. Teachers and researchers construct goals for what they want each research group to accomplish. The jigsaw method is dependent on each group of students' understanding and conveying their material to others. It is imperative, for example, that the students responsible for photosynthesis understand this difficult concept that is a mainspring of the entire food chain unit. If students do not achieve robust understanding without aid, the teacher must engineer methods that ensure that understanding.

Teachers in the program are also made aware of common misconceptions that students may harbor concerning, for example, the nature of plants (Bell, 1985) 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 confront students with 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.

Clearly, we do not advocate untrammeled discovery learning (Brown, 1992). Although there is considerable evidence that didactic teaching leads to passive learning, by the same token unguided discovery can be dangerous too. 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, thus blinding themselves to essential notions of randomness and spontaneity (the teleological stance: Keil, 1989; Mayr, 1988). Teachers are encouraged to see these common problems as fruitful errors, waystages on the route to mature understanding that they can manipulate and direct in useful ways.

But the role of the teacher in discovery learning classrooms is problematic. It is still largely uncharted. Invoking comfortable metaphors such as the teacher as coach does not tell us how and when the teacher should coach. We know that challenging students' assumptions, providing them with counterexamples to their own rules, and so on are good instructional activities; but how intrusive should the teacher be? When should she guide? When should she teach? When should she leave well enough alone? In short, how can the teacher foster discovery and at the same time furnish guidance?

We encourage our teachers to adopt the middle ground of *guided discovery*, but this role is difficult to maintain. Consider the position of a teacher who knows something the students do not. Here she is in the position of making a judgment about whether to intervene. She must decide whether the problem centers on an important principle or involves only a trivial error that she can let pass for now. Consider a teacher who does not know the answer, or one who may share the students' puzzlement or misconception. She is first required to recognize this fact (which she 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 demands competence and confidence. The connection to a wider community of learners and experts that electronic mail provides encourages classroom teachers to admit that they do not know and seek help, thereby modeling this important learning strategy for their students.

Guided learning is easier to talk about than do. It takes clinical judgment to know when to intervene. The successful teacher must continually engage in on-line diagnosis of student understanding. She must be sensitive to current overlapping zones of proximal development, where certain students are ripe for new learning. She must renegotiate zones of proximal development so that still other students might become ready for conceptual growth. She must appropriate and capitalize on emergent ideas and help refine them and link them to enduring themes. Determining the region of sensitivity to instruction (Wood, Bruner, & Ross, 1976) for the whole class, a subgroup, or an individual child, on-line and unaided, if it is not magic (Bandler & Grinder, 1975), is certainly a work of art. 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 would not be reached without expert guidance (Brown, 1992; Bruner, 1969).

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, the teacher is the master craftsperson of learning whom they must emulate. In this role, the teacher models scientific inquiry through thought and real experiments. Children witness teachers learning, discovering, doing research, reading, writing, and using computers as tools for learning, rather than lecturing, managing, assigning work, and controlling the classroom exclusively.

The teacher's job is also to encourage habits of mind by which children are encouraged to adopt, extrapolate, and refine the underlying themes to which they are exposed. Bruner (1969) argues that 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. (p. 124)

But again, this requires not untrammeled discovery learning, but the expert guidance of a gifted teacher.

The role of the curriculum. The teacher's role is a complex one; she is constantly faced with seemingly conflicting responsibilities: She 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. This brings us to the thorny question of the role 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 must 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 the biology classroom, we concentrate on interdependence and adaptation. In the environmental science classroom, themes might include balance, competition and cooperation, and predator–prey relations that are central to an understanding of ecosystems. In the health education classroom, an understanding of disease and contagion is central. Although we aim at depth over breadth in coverage, we decided against recourse to biochemical substrata with middle school children. Instead, the students are invited into the world of the nineteenth-century naturalist, where they read, do research, conduct experiments, participate in field trips, and engage in various forms of data collection and analysis around the central repeating themes.

In choosing our curriculum units we try to focus on a few "lithe and beautiful and immensely generative" ideas, to use Bruner's classic phrase (Bruner, 1969, p. 121). We believe that it is unreasonable to expect children to reinvent these ideas for themselves. Providing expert guidance, in the form of teachers, books, and other artifacts, is one of the prime responsibilities of schooling. Immensely generative ideas may be few, and the idea behind education is to point children in the right direction so that they might discover and rediscover these ideas continuously, so that on each encounter the theme will be recognized and students may deepen their understanding in a cyclical fashion (Bruner, 1969). Certain central themes are seeded early by the teacher and revisited often.

While seeding the environment with generative ideas, the teacher is also free to encourage the knowledge-majoring activities of individual children or groups of mavericks who choose to do even more specialized work than that invited by the curriculum topics shared by all. Because of these self-initiated tangents, no two classes cover exactly the same material, even though they are seeded by the same teacher talk and the same supports, including books, videos, and experiments. For example, one sixth-grade class devoted two weeks of research to uncovering the history and effects of DDT because DDT had been featured in a play they had enacted and in a passage they had been reading in reciprocal teaching sessions. The classroom teacher was not prepared for this departure; her first response was to urge them on to the next part of the curriculum that she had scheduled; but then she capitalized on their knowledge and interest in order to introduce the higher-level theme of systemic disruption in food webs using their DDT knowledge as a basis, a good example of mutual appropriation.

Similarly, in one sixth-grade class, certain children became deeply involved with 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. A member of the group studying elephants became fixated on the amount of food consumed, first, by his animal, the elephant, 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, as the student wrote, "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 talked about in most subsequent discussions.

Two girls studying whales became interested in fertility rates and the fate of low birth weight babies. They discovered that one reason certain species of whales are endangered is that their reproduction rate has slowed dramatically. They also discovered that the peregrine falcon's inability to produce eggs with protective shells was a cause of endangerment. Talking to an adult observer, they asked about the fate of low birth weight babies, because "they don't have those little baby boxes [incubators] in the wild and can't feed them with tubes." They decided that low birth weight babies would be "the first to die" – "good prey for predators." Again, 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 given species had and, more complexly, as the notion of reproductive strategies in general. The teacher appropriated the 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 encouraged them to consider the deeper general principles of metabolic rate, and survival and reproductive strategies.

The role of technology. Our classrooms have the support of sophisticated state-of-the-art technology, including computers and video materials. Although some have argued that technology has had, and will have, little impact on the way teachers teach (Cuban, 1986), others have argued that the availability of supportive computer environments could have a fundamental effect on learning and teaching in classrooms (Schank & Jona, 1991). Currently, computers are used in grade school primarily to replace teachers as managers of drill and practice or to teach children to program. But the problem with these activities is that most people do *not* use computers in this fashion – they use personal computers as just that, personal tools to aid learning. They use word processing and desktop publishing (including ready access to graphics and perhaps spreadsheets). They set up and access their knowledge files. They use electronic mail. We believe this is how grade school children should initially view computers – as invaluable tools for their own sustained learning: building up a portfolio, maintaining and revising their files, using graphics tools, and networking. We want them to harness technology as a means of enhancing their thinking – planning and revising their learning goals, monitoring and reflecting on their own progress as they construct personal knowledge files and share a communal database.

Although several extremely powerful computer environments have been developed (see particularly CSILE, Scardamalia & Bereiter, 1991), we chose to work with commercially produced and stable software available to any school and capable of running on relatively inexpensive hardware (for details see Campione et al., 1992). This computer environment was designed to (1) simplify student access to research materials, including books, magazines, videotapes, and videodiscs; (2) support writing, illustrating, and revising texts; (3) allow for data storage and management; and (4) facilitate communication within and beyond the classroom.

We will discuss two aspects of the computer environment critical to a discussion of distributed expertise: (1) computer activities that facilitate thinking and (2) computer activities that help shape thought.

1. *Facilitating thinking.* We will limit our attention to two features of the environment that encourage the kinds of thinking we wish to facilitate in the classroom. These involve two applications, QuickMail and Browser.

Our students make use of a commercially available, child-friendly electronic mail package called "QuickMail." With QuickMail, students can send messages electronically to members of the classroom, to their teacher, and to mentors at the university and elsewhere in the community. Communication does not rely on the memorization of elaborate codes or typing efficiency; to make contact with another individual or group, the child needs only to "click" on an icon visually depicting the target – for example, a picture of a peer or adult, or a token of a group (e.g., a dolphin for the Dolphins). In addition, the system is customized by the design of special forms that facilitate specific interactions – for example, a "permission to publish" form that students use when they wish to publish in the system or a "junior scientist to senior scientist" message form. It also provides a simple way for students to enclose within their messages documents created with other applications.

The use of QuickMail was rapidly established only in classrooms where the teacher provided support and encouragement and, most important, modeled the use of the application herself. It was also rapidly established as part of classroom practice when there was a clear purpose for the activity, one such purpose being the necessity to communicate with community members outside the classroom.

QuickMail use was only sporadic if the classroom teacher did not use it herself, or when communication was restricted to those within the same four walls. Indeed, why would one QuickMail a query to a peer sitting five feet away?

In one successful QuickMail classroom, the teacher (MR) modeled the use of computers on a daily basis, spending a minimum of one hour a day using the computers in the classroom, communicating through QuickMail, or doing miscellaneous writing or planning tasks (ranging from organizing a kickball game to preparing homework assignments). As she put it, "They see me using the computer all the time." MR's attitude toward both her own and her students' use of computers was extremely positive, and there was a strong sense in the classroom of the teacher enthusiastically *joining* with the students in the use of the computers. MR overtly encouraged and supported student use. She talked explicitly and often about the computer as a tool that can make many different activities easier. She explained:

> I really want the kids to see that they're . . . using the computer like they would use a pencil. Only it's more high tech, so it does some things nicely that they would otherwise have to do using a more laborious process. . . . It's simply ways to make what you already are going to do easier . . . so you can go about the business of learning what you want to learn. . . . And I really don't want them to think that I couldn't do this unless I had a computer, but because I have a computer, I can do that much more.

MR also had early and consistent recourse to the use of QuickMail herself, corresponding with the students concerning their written projects, assignments, and often their personal life. She also corresponded with fellow members of the research team at Berkeley in the presence of students, thereby modeling the transmission of queries and comments and the receipt of replies. Students readily began communicating with one another and the university staff, due in good part to this modeling and encouragement. As a result the students used electronic mail as a routine part of classroom life.

QuickMail became another forum for creating zones of proximal development involving students and the community at large. For example, consider the following exchange between a graduate student (MJ) with a biology background and a group of students (Da 4 Girlz). The interaction was initiated by the students, who asked about 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.

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

The graduate student 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. On receiving yet another request for information from the persistent AM, the graduate student re-enters 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 insects, such as tarantulas, 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, the student again adopts the easier path of asking for direct information. "I'm not really sure if a tarantula hibernates. What do you think?" to which the graduate student 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, 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. The graduate student has seeded 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 understands warm-bloodedness. QuickMail has exciting possibilities as a medium for sustaining and expanding zones of proximal development and is an essential feature of our learning environment, freeing teachers from the burden of being sole guardians of knowledge and allowing the community to extend beyond the classroom walls.

QuickMail is also used frequently as a private means of discussing personal dilemmas, both among students and between students and the classroom teacher. Less often such personal queries arise in discourse with outside experts. Buried in a series of legitimate questions about biological issues, a student asks a researcher: "I also wanted to know how you came about making your career about science do you really like science or do you have to know someone special to get into the field of science?" The response, again tactfully buried in legitimate science discourse, was:

I just got interested in science when I was in grade school, and decided that was what I was going to try to do when I grew up, and it worked! To answer one of your questions, you don't have to know anyone to get into science, you just have to have an interest in it and the motivation to work hard to get good at it. Actually, I didn't know any scientists when I was young, and no one in my family had ever gone to University before I did. Since you are working with the University now, you know more scientists than I did.

QuickMail is an indispensable extension of the learning community outside the classroom walls, and not just in terms of content-specific expertise.

2. *Shaping thought.* The second application, "Browser," enhances and organizes shared thinking. We designed Browser (written in HyperCard 2.0) for several reasons. First, it allows filing of, and searching through, documents by topics (e.g., animal defense mechanisms) and themes (e.g., camouflage, mimicry). Browser is a hierarchical system featuring three main windows, one providing a list of topics, a second the themes associated with each topic, and the third a list of resources. Opening the resources window results in a list of all the titles available. Use of the themes and topics windows pares down that list considerably. For example, if a student opens the topics window and highlights animal defense mechanisms, the resources display is reduced to all entries having to do with that topic. If the themes window is also opened, and camouflage selected, the list of entries is further reduced to those satisfying both constraints. Thus, to use Browser effectively, students must specify in some detail what information they need; that is, they must pose their research question sharply. This is not a skill entering students possess. Their initial uses of Browser consist almost exclusively of opening the resources window and scanning the set of titles in an attempt to find something

that may be relevant. It is only with prompting and practice that they come to understand the need for specifying their research needs in sufficient detail to organize and restrict their search. In this way, Browser is one of several aspects of the environment that lead students to appreciate the need for, and practice, formulating specific questions.

Given a topic and theme, Browser generates a list of titles and indicates the media type (text, magazine, videotape, or videodisc) of each entry. If a specific selection is stored on the file server, the student can call it up directly. Browser also allows students to expand the system by generating their own themes and topics and by writing their own summaries and comments on new selections. We begin by providing examples of summaries for some of the basic entries, but after the students become familiar with the system, they generate and discuss their own summaries and comments. Furthermore, when students choose to publish their own work, they are required to generate key words, in the form of general topics and subthemes, and to provide a summary. Over time, the library becomes progressively more annotated by the students themselves, with their entries providing us with important data concerning their ability to cross-classify and summarize and indicate what they see as significant. Because of student authoring, no two classes generate the same Browser.

We emphasize again that the very act of using Browser serves as a scaffold to certain forms of thought processes such as hierarchical organization and double classification. In this way aspects of the computer environment shape as well as augment the shared knowledge base of the class. We first noticed the way in which increasing competence with the software affected the organization of thought in an earlier experiment when the children had access to only HyperCard and Microsoft Word (Brown & Campione, 1990). Limited exposure to HyperCard was not successful. The method of organization was not transparent to children, and it encouraged some well-known bad research and writing habits of children this age, such as the copy-delete strategy whereby students merely copy sections from a text, deleting what they regard as uninformative (Brown & Day, 1983). Once a card was filled, that was the end of that thought. The idea that a thought could extend for more than one card was never entertained. And the organization structure of the cards was such that it initially

precluded the emergence of sophisticated text structures. Each card contained all that was known, for example, about a particular animal; and texts consisted of the random linking together of a set of independent cards. The complex linking features of the software were never exploited successfully. An optimistic child described organization in HyperCard as being "like a collage," but more representative was the comment, "Ms. S, I don't have a HyperCard mind."

Although the virtues of HyperCard were not readily transparent to the majority of the children, the file folder system of the regular Macintosh interface was iconically powerful. In order to find their notes on, for example, the crested rat, students had to know that this animal provided an example of an animal defense mechanism, under which topic they needed to enter the file on mimicry, and to know that it was necessary to refer to the file on visual mimicry, and only then would they find the animal in question, one that visually mimics a skunk to defend itself. Forced to organize information into files within files within files, the children regularly practiced the use of hierarchical organization. These search activities involving hierarchical organization were appropriated for use in writing. Student-generated texts progressed from having no discernible organizational structure to having quite sophisticated hierarchies (Campione et al., 1992). Hierarchical search activities, practiced over a long period of time, reinforced hierarchical organizational structure, and such practices transformed the organization of writing samples. In this case the zone of proximal development included students and machines, rather than exclusively people. Certain interactions with technology can powerfully shape thought.

The role of assessment. The final feature of our design experiments centers on the equally thorny problem of assessment. How does one maintain standards of accountability – to students, teachers, and parents, to school officials who are responsible for the students' progress, and to fellow scientists – while at the same time keeping the social contract with students, who are encouraged to view themselves as co-equal participants in a community of sharing? This is a difficult tightrope to walk, and our approach has been to be honest with the children and to allow them to participate in the assessment process as much as possible.

In addition to fairly traditional tests, we feature a variety of dynamic assessments (Campione, 1989; Campione & Brown, 1990) of the students' developing knowledge. Dynamic assessment methods present children with problems just one step beyond their existing competence and then provide help as needed for them to reach independent mastery. Again, competence is fostered in social interactions before individual mastery is expected. The degree of aid needed, both to learn new principles and to apply them, is carefully calibrated and measured. The required amount of aid provides a much better index of students' future learning trajectories in a domain than do static pretests. In particular, the ease with which students apply, or transfer, principles they have learned is regarded as an indication of their understanding of those principles; and this transfer performance is the most sensitive index of a student's readiness to proceed within a particular domain (Brown, Campione, Webber, & McGilly, 1992).

The dynamic assessment procedure is based on the same loosely interpreted Vygotskian theory that provided the underpinning for the development of reciprocal teaching. As can be seen in Table 7.2, both are based on the same type of learning theory but differ in their primary goals – assessing a student's level of understanding or enhancing that level. The primary difference rests in the nature and timing of the adult (expert) aid. In assessment, aid is metered out only as needed, permitting students to demonstrate independent competence when they can and permitting adults to gauge the extent of that competence. In the reciprocal teaching mode, help is given opportunistically as a result of the teacher's on-line diagnosis of need. Common to this theoretical approach to both diagnosis and instruction is the central notion of supportive contexts for learning. Four main principles are involved in the design of the dynamic assessments: (1) Understanding procedures rather than just speed and accuracy are the focus of assessment and instruction. (2) Expert guidance is used to reveal as well as promote independent competence. (3) Microgenetic analysis permits estimates of learning as it actually occurs over time. (4) Proleptic teaching (Stone & Wertsch, 1984) is involved in both assessment and instruction, for both aim at one stage beyond current performance, in anticipation of levels of competence not yet achieved individually but possible within supportive learning environments.

Table 7.2. *Assessment and instruction in a zone of proximal development*

Main similarities	
Based (loosely) on Vygotsky's learning theory	
Guided collaboration with expert feedback	
Strategy modeling by experts (apprenticeship model)	
Externalization of mental events via discussion formats	
On-line assessment of novice status	
Help given, responsive to student needs	
Aimed at problem solving at the level of metacognition	
Understanding measured by transfer, flexible use of knowledge	
Main differences	
Dynamic assessment	Reciprocal teaching
Goal: Individual assessment	Goal: Collaborative learning
Test: Knowledge and strategies	Teach: Knowledge and strategies
Aid: Standardized hints	Aid: Opportunistic
Hints: Hard to easy to measure student need	Hints: Easy to hard to scaffold student progress

As just one concrete example of this approach, we will describe a clinical interview designed to uncover students' biological knowledge. (For a discussion of dynamic assessment of emergent computer expertise, see Campione et al., 1992.) The students regarded participation in this interview as privileged one-on-one time with a visiting expert. At some level, of course, the students must have known it was a test, but the classroom ethos, involving the gaining and sharing of expertise, was such that the children enjoyed the chance to act as consultants and to discuss difficult concepts with the interviewer (DA; see Ash, 1991, for more details).

In the clinical interview, a series of key questions is raised concerning, for example, the food chain or adaptation. First, the interviewer elicits basic expository information. If the student cannot answer adequately, the interviewer provides hints and examples as necessary to test the student's readiness to learn the concept. If the student seems knowledgeable, the experimenter might question the student's understanding by introducing *counterexamples* to the student's beliefs (Is a mushroom a plant? What about yeast?), and again if appropriate, she might ask the student to engage in *thought experiments* that demand novel uses of the information. For example, when a student has sorted pictures of animals into herbivores and carnivores, and provided a good description of the categories, she 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?" Students previously judged knowledgeable on the basis of their expository information can be 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 invoke notions of form and function, such as properties of the digestive tract, to support the assertion that cheetahs could not change. These extension activities of thought experiments and counterexamples are far more revealing of the current state of students' knowledge than their first unchallenged answers, which often provide an overly optimistic picture of their knowledge.

Consider the following excerpts from John, a sixth-grader. During the pretest interview, John mentioned speed, body size, mouth size, and tearing teeth as functional physical characteristics of carnivores. He seemed to have the carnivore–herbivore distinction down pat. But when presented with the cheetah thought experiment, he mused: " . . . Well, I mean if people can, like, are vegetarians, I mean I think a cheetah could change."

This is a good example of a common reasoning strategy: personification as analogy (Carey, 1985; Hatano & Inagaki, 1987). When asked how this might happen, he said:

> 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.

When asked if it would be easier for a baby cheetah to eat grass, he responded:

> 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 . . . but I think it would be easier . . . but then if it happens for a long time, then the animals come back, [the gazelles return], then it probably would have lost its speed, because they wouldn't have to run. . . . Yeah, and they'd get used to the grass and not care about the animals, because along the line they would forget.

During the posttest clinical interview six months later, when asked the same question, John makes complex analogies to the cow's intestinal system, arguing that herbivore digestive tracts are more complicated than those of carnivores. By knowing an animal's diet, he argues, he would be able to predict its digestive tract length and how long digestion might take, and vice versa.

This time, when confronted with a variant of the cheetah thought experiment, John responded:

> No . . . no, their digestive system 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 if baby cheetahs could survive by eating grass, John asserted that they would probably be the first to die.

These responses are in distinct contrast to those given to the same questions during the pretest. John has abandoned personification (Hatano & Inagaki, 1987) as an explanation ("Humans can do it so cheetahs can too") and replaced it with a form–function justification. Thrown a novel twist on the old question – whether deer might be able to eat meat if there were no longer grass, the newly confident John favored the interviewer with a broad smile and said: "Nice try . . . the digestive tract of the deer is too complicated and also the teeth wouldn't be able to grind meat."

Another example of the rich picture that can be drawn from dynamic assessment and thought experiments comes from Katy, a sophisticated seventh-grader who gave a textbook-perfect description of photosynthesis that would in traditional tests certainly be taken as an indication that she fully understood the basic mechanisms. She was then asked, "What would happen if there were no sunlight?" Katy's response never included the critical information that since plants make food with the sun's energy, a serious reduction in the availability of sunlight would disrupt the entire food chain. Instead she concentrates on light to see with:

> That would kill off the plants, beetles, and . . . um . . . nocturnal things would be OK. The dayturnal things . . . snakes, rabbits, hares . . . would be all right, they

could be nocturnal. But the dayturnal things would need sunlight to see . . . couldn't find their food in the dark and would eventually starve to death. Hawks would also die out, but owls are nocturnal . . . would be able to see at night and . . . um . . . raccoons would probably be near the top of the food chain.

Katy clearly had not understood the basic place of photosynthesis as the mainspring of life. She could repeat back the mechanisms and form food chains when directly asked, but she could not yet reason flexibly with her newfound knowledge.

Using these thought experiments, we can track the development not only of the retention of knowledge, but also of how fragile or robust that knowledge is and how flexibly it can be applied. The philosophy of negotiation and appropriation within a zone of proximal development is just as apparent in our assessment procedures as in our classroom practices. Indeed, these clinical assessments are collaborative learning experiences in their own right. As such, the line between assessment and instruction becomes increasingly blurred, intentionally so (Campione, 1989).

Authentic school activity

We began this chapter by raising the question: What constitutes authentic activity in the early years of schooling? We argued that it is surely impractical to suggest that grade schools at least could become apprenticeship sites for inducting children into the community practices of mathematicians or historians. Most of the children who take part in our environmental science classrooms are not intending to become biologists or environmental scientists, and it is not intended that they should. But if they develop into individuals able to evaluate scientific information critically and to learn about new developments in science, then we would be more than satisfied. In regard to the continuity between school and authentic practice, we believe the best we can do is to avoid obvious discontinuity with the cultures of practicing scientists. To this end, we introduce students to the world of working scientists through visits and electronic mail, and we immerse them in the discourse structures of inquiry, conjecture, evidence, and proof. Furthermore, we encourage them to invent real and thought experiments that they share with the community at large via publications, seminars, and science fairs. Some of the best examples of continuity between grade school practices and disciplinary-based discourse modes come from work in grade school mathematics (Lampert, 1986; O'Connor, 1991), examples we try to emulate in grade school science. We want students to be practicing members of a science community to the extent possible; hence, the metaphor of the nineteenth-century naturalist guides our activities.

Although we attempt to avoid obvious discontinuity in activities between grade school science and legitimate scientific practice to the degree that we are able (the children have no biochemical knowledge), we believe that the true apprenticeship in schools is to a community of scholars. Although many authentic adult activities are disciplinary-bound, there are domain-independent learning activities that do allow the intelligent novices more ready access to a new domain and the subsequent freedom to select a community of practice of their choosing (Brown et al., 1983).

A common translation of the notion of cognitive apprenticeships is that students be apprenticed to the community practice of, say, mathematics (Collins, Brown, & Newman, 1989). But a more compelling argument is to take the title seriously and think in terms of "thinking" or "learning" apprenticeships. We believe that "thinking apprenticeships" should be the authentic activity of grade school life, although we recognize that this position is controversial. During their tenure in school, young children should ideally be absorbed into a community of research practice where they gradually come to adopt the ways of knowing, cultural practice, discourse patterns, and belief systems of scholars. We know that we have made progress toward this goal when a leading scholar in the field, looking at videotapes of our students, exclaims, "But they look just like us; it looks like a graduate seminar." Schools should provide a breeding ground for young scholars where they can be prepared for a career as lifelong intentional learners.

The central theoretical ideas underpinning our classroom design experiments (Brown, 1992; Collins, in press) are those of mutual appropriation and negotiation within multiple overlapping zones of proximal development. Life in our science classrooms involves situated negotiation and renegotiation of ideas, terms, definitions, and so on (O'Connor, 1991), so that something like a common voice (Wertsch, 1991) and a common knowledge base (Edwards & Mercer, 1987) emerge over time. This common voice evolves continuously via "situated negotiation and renegotiation of meaning" (Lave & Wenger, 1991). Participants in the community are free to appropriate "ideas in the air" and transform these ideas via personal interpretation and incorporation. Within the same classroom, participants pass in and out in multiple zones of proximal development as they appropriate ideas and ways of knowing that are ripe for harvesting. Although a common voice emerges, individuals develop ownership of separate parts of that common knowledge through a process of majoring, the intentional focusing on aspects of the system that a learner decides to specialize in. Distributed expertise is a central facet in authentic communities of scientific practice – hence the need to share knowledge among scientists via papers, conferences, electronic mail, and other means. This distributed expertise is no less desirable for grade school classrooms, when authentic learning is the name of the game, than it is for practicing scientists. The idea that all children of a certain age in the same grade should acquire the same body of knowledge at the same time, an essential assumption underlying mass assessment, is one of the reasons that contemporary school activities are to a large part inauthentic.

Conclusion

In this chapter we have described our attempt to foster communities of learning in the classroom, practices we believe are the legitimate activities of an institution that ideally came into being to promote learning. 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. Expertise is shared and distributed within the community by design and by happenstance. 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. When they work, and they do not always work, our 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.

References

Aronson, E. (1978). *The jigsaw classroom.* Beverly Hills, CA: Sage.

Ash, D. (1991). *A new guided assessment of biological understanding.* Unpublished manuscript, University of California, Berkeley.

Bandler, R., & Grinder, J. (1975). *The structure of magic.* Palo Alto, CA: Science & Behavior Books.

Barnes, D., & Todd, F. (1977). *Communication and learning in small groups.* London: Routledge & Kegan Paul.

Bell, B. (1985). Students' beliefs about plant nutrition: What are they? *Journal of Biological Education, 19,* 213–18.

Bereiter, C. (1985). Toward a solution of the learning paradox. *Review of Educational Research, 55,* 201–26.

Bloor, D. (1991). *Knowledge and social imagery.* Chicago: University of Chicago Press.

Bordieu, P. (1972). *Outline to a theory of practice.* Cambridge University Press.

Brown, A. L. (1992). Design experiments: Theoretical and methodological challenges in creating complex interventions in classroom settings. *Journal of the Learning Sciences, 2*(2), 141–78.

Brown, A. L., Bransford, J. D., Ferrara, R. A., & Campione, J. C. (1983). Learning, remembering, and understanding. In J. H. Flavell & E. M. Markman (Eds.), *Handbook of child psychology* (4th ed.), *Vol. 3: Cognitive development* (pp. 77–166). New York: Wiley.

Brown, A. L., & Campione, J. C. (1990). Communities of learning and thinking, or A context by any other name. *Human Development, 21,* 108–26.

(in press). Restructuring grade school learning environments to promote scientific literacy. In *Restructuring learning: Analysis and proceedings of the annual conference of the Council of Chief State School Officers.* San Diego, CA: Harcourt Brace Jovanovich.

Brown, A. L., Campione, J. C., Webber, L. S., & McGilly, K. (1992). Interactive learning environments: A new look at assessment and instruction. In B. R. Gifford & M. C. O'Connor (Eds.), *Changing assessments: Alternative views of aptitude, achievement and instruction* (pp. 121–211). Boston: Kluwer.

Brown, A. L., & Day, J. D. (1983). Macrorules for summarizing texts: The development of expertise. *Journal of Verbal Learning and Verbal Behavior, 22*(1), 1–14.

Brown, A. L., & Palincsar, A. S. (1989). Guided, cooperative learning and individual knowledge acquisition. In L. B. Resnick (Ed.), *Knowing, learning, and* *instruction: Essays in honor of Robert Glaser* (pp. 393–451). Hillsdale, NJ: Erlbaum.

Brown, A. L., & Reeve, R. A. (1987). Bandwidths of competence: The role of supportive contexts in learning and development. In L. S. Liben (Ed.), *Development and learning: Conflict or congruence?* (pp. 173–223). Hillsdale, NJ: Erlbaum.

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher, 18,* 32–42.

Brumby, M. (1979). Problems in learning the concept of natural selection. *Journal of Biological Education, 13,* 119–22.

Bruner, J. S. (1969). *On knowing: Essays for the left hand.* Cambridge, MA: Harvard University Press.

Campione, J. C. (1989). Assisted assessment: A taxonomy of approaches and an outline of strengths and weaknesses. *Journal of Learning Disabilities, 22,* 151–65.

Campione, J. C., & Brown, A. L. (1990). Guided learning and transfer. In N. Frederiksen, R. Glaser, A. Lesgold, & M. Shafto (Eds.), *Diagnostic monitoring of skill and knowledge acquisition* (pp. 141–72). Hillsdale, NJ: Erlbaum.

Campione, J. C., Brown, A. L., & Jay, M. (1992). Computers in a community of learners. In E. DeCorte, M. Linn, H. Mandl, & L. Verschaffel (Eds.), *Computer-based learning environments and problem solving* (NATO ASI Series F: Computer and Systems Sciences), Vol. 84, pp. 163–92. Berlin: Springer.

Carey, S. (1985). *Conceptual change in childhood.* Cambridge, MA: MIT Press.

Cazden, C. (1981). Performance before competence: Assistance to child discourse in the zone of proximal development. *Quarterly Newsletter of the Laboratory of Comparative Human Cognition, 3,* 5–8.

Cole, M., & Bruner, J. S. (1971). Cultural differences and inferences about psychological processes. *American Psychologist, 26,* 867–76.

Collins, A. (in press). Toward a design science of education. In E. Scanlon & T. O'Shea (Eds.), *New directions in educational technology.* New York: Springer.

Collins, A., Brown, J. S., & Newman, S. (1989). Cognitive apprenticeship: Teaching the crafts of reading, writing and mathematics. In L. B. Resnick (Ed.), *Knowing, learning, and instruction: Essays in honor of Robert Glaser* (pp. 453–94). Hillsdale, NJ: Erlbaum.

Collins, A., & Stevens, A. (1982). Goals and strategies of inquiry teachers. In R. Glaser (Ed.), *Advances in instructional psychology* (Vol. 2, pp. 65–119). Hillsdale, NJ: Erlbaum.

Cuban, L. (1986). *Teachers and machines: The classroom of technology since 1920.* New York: Teachers College Press.

Dewey, J. (1902). *The child and the curriculum.* Chicago: University of Chicago Press.

Edwards, P., & Mercer, N. (1987). *Common knowledge.* London: Open University Press.

Erickson, F., & Schultz, J. (1977). When is a context? Some issues and methods on the analysis of social competence. *Quarterly Newsletter of the Institute for Comparative Human Development, 1,* 5–10.

Fish, S. (1980). *Is there a text in this class? The authority of interpretive communities.* Cambridge, MA: Harvard University Press.

Fodor, J. (1980). On the impossibility of acquiring "more powerful" structures. In M. Rattelli-Palmarini (Ed.), *Language and learning: The debate between Jean Piaget and Noam Chomsky* (pp. 142–62). Cambridge, MA: Harvard University Press.

Gardner, H. (1991). *The unschooled mind.* New York: Basic Books.

Goodwin, C. (1987, June). *Participation frameworks in children's argument.* Paper presented at the International Interdisciplinary Conference on Child Research. University of Trondheim, Norway.

Hall, G. S. (1881). The contents of children's minds. *Princeton Review, 11,* 249–72.

Hatano, G., & Inagaki, K. (1987). Everyday biology and school biology: How do they interact? *Newsletter of the Laboratory of Comparative Human Cognition, 9,* 120–8.

Heath, S. B. (1983). *Ways with words.* Cambridge University Press.

Hoffding, H. (1892). *Outlines of psychology* (M. E. Lowndes, Trans.). London: Macmillan Press.

Keil, F. (1989). On the development of biologically specific beliefs: The case for inheritance. *Child Development, 60,* 637–48.

Lampert, M. (1986). Knowing, doing, and teaching multiplication. *Cognition and Instruction, 3*(4), 305–42.

Lave, J. (1988). *Cognition in practice: Mind, mathematics and culture in everyday life.* Cambridge University Press.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation.* Cambridge University Press.

Lempke, J. L. (1990). *Talking science.* Norwood, NJ: Ablex.

Mayr, E. (1988). *Toward a new philosophy of biology.* Cambridge, MA: Harvard University Press.

Mehan, H. (1979). *Learning lessons: Social organization in the classroom.* Cambridge, MA: Harvard University Press.

Michaels, S., & O'Connor, M. C. (in press). Literacy as reasoning within multiple discourses. In *Restructuring learning: Analysis and proceedings of the annual conference of the Council of Chief State School Officers.* San Diego, CA: Harcourt Brace Jovanovich.

Minstrell, J. A. (1989). Teaching science for understanding. In L. B. Resnick & L. E. Klopfer (Eds.), *Toward the thinking curriculum: Current cognitive research* (pp. 129–49). The Association for Supervision and Curriculum Development.

Moschkovich, J. (1989, April). *Constructing a problem space through appropriation: A case study of tutoring during computer exploration.* Paper presented at the meetings of the American Educational Research Association, San Francisco.

Newman, D., Griffin, P., & Cole, M. (1989). *The construction zone.* Cambridge University Press.

Ochs, E. (1991). Indexicality and socialization. In J. W. Stigler, R. A. Shweder, & G. Herdt (Eds.), *Cultural psychology: Essays on comparative human development* (pp. 287–308). Cambridge University Press.

O'Connor, M. C. (1991). *Negotiated defining: Speech activities and mathematical literacies.* Unpublished manuscript, Boston University.
Palincsar, A. S., & Brown, A. L. (1984). Reciprocal teaching of comprehension-fostering and monitoring activities. *Cognition and Instruction, 1*(2), 117–75.
Resnick, L. B. (1987). *Education and learning to think.* Washington, DC: National Academy Press.
Rogoff, B. (1990). *Apprenticeship in thinking.* Oxford: Oxford University Press.
Rutherford, M. (1991). *Second language learning in a "community of learners" classroom.* Unpublished manuscript, University of California, Berkeley.
Scardamalia, M., & Bereiter, C. (1991). Higher levels of agency for children in knowledge building: A challenge for the design of new knowledge media. *Journal of the Learning Sciences, 1,* 37–68.
Schank, R. C., & Jona, M. Y. (1991). Empowering the student: New perspectives on the design of teaching systems. *Journal of the Learning Sciences, 1,* 7–36.
Schoenfeld, A., Smith, J., & Arcavi, A. (in press). Learning: The microgenetic analysis of one student's evolving understanding of a complex subject matter domain. In R. Glaser (Ed.), *Advances in instructional psychology* (Vol. 4). Hillsdale, NJ: Erlbaum.
Stone, C. A., & Wertsch, J. V. (1984). A social interactional analysis of learning disabilities remediation. *Journal of Learning Disabilities, 17,* 194–9.
Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes* (M. Cole, V. John-Steiner, S. Scribner, & E. Souberman, Eds. and Trans.). Cambridge, MA: Harvard University Press.
Wertsch, J. V. (1991). *Voices in the mind.* Cambridge University Press.
Wineburg, S. (1989). A response to Brown, Collins and Duguid. *Educational Researcher, 18,* 44–8.
Wood, D., Bruner, J., & Ross, G. (1976). The role of tutoring in problem solving. *Journal of Child Psychology and Psychiatry, 17,* 89–100.

8 On the distribution of cognition: some reflections

Raymond S. Nickerson

A discussant of a book composed of chapters by many authors can work toward any of several objectives: summarization, clarification, amplification, reconciliation, analysis, or critique from a particular perspective. My objective in the following comments is both modest in comparison with these possibilities and opportunistic. It is modest in that the comments do not serve a specific theoretical agenda and are not made in the hope of changing anyone's mind about any burning theoretical issues. It is opportunistic in that I selectively focus on several points or themes that struck me as especially interesting, for whatever reasons. I make no effort to review or critique the chapters in a comprehensive way.

I take my cue from Pea's observation in Chapter 2 that the idea of distributed intelligence is not a theory of mind or of anything else so much as it is a "heuristic framework for raising and addressing theoretical and empirical questions." I believe it serves that purpose quite well. The idea of intelligence (knowledge, cognition) being distributed in a group, or in artifacts, customs, and situations, is in my view an interesting one not so much because of any questions it might answer as because of the many it raises.

I found the foregoing chapters thought-provoking indeed. Reading them set me to thinking about a variety of questions. What is new in the new look at cognition? What is insightful and revealing? On the assumption that the concept of distributed cognition and the ideas associated with it represent a genuinely new point of view, what follows? What are the implications for education?

I am grateful to David Perkins and Gavriel Salomon for helpful comments on a draft of this chapter.