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Higher Levels of Agency for Children in Knowledge Building: A Challenge for the Design of New Knowledge Media

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Although adults and children both have zones of proximal development in which more knowledgeable others play essential roles, there is a difference in executive control that is most salient in question-answer dialogue. Adult learners typically ask questions based on their perceived knowledge needs, whereas with school children, questions are typically asked by the teacher, based on the teacher's perception of the child's needs. Evidence shows that children can produce and recognize educationally productive questions and can adapt them to their knowledge needs. The challenge is to design environments in which students can use such questions to guide their building of knowledge, thus assuming a higher level of agency in learning. Computer Supported Intentional Learning Environments (CSILE), a computer-supported knowledge medium designed to support intentional learning, is described, with illustrations of children's use of it in cooperative knowledge building.

The proposition that students construct their own knowledge lends itself readily to over interpretation and, in the extreme case, to a dangerously romantic optimism. As Vuyk (1981) pointed out, constructivism is a necessary consequence of taking an intentional stance toward cognition. It entails no empirical claims about the abilities of children, the necessity or dispensibility of instruction, or anything else that might be put to the test. In practice, however, constructivism has been a watchword for all kinds of efforts to give children more agency in the learning process. It has been seen as opposed to traditional didactic approaches to education, which seem to be based on an assumption of direct transfer of knowledge from teacher to student, without an intervening constructive process.

The relationship between the ideas of constructivism and of agency in the learning process can vary greatly. At one extreme, in behaviorally oriented social psychology, there is an idea of student as agent without any accompanying notion of student as constructor of knowledge (e.g., Mahoney & Thoresen, 1974). Here the idea of agency is primarily that of students' responsibility for their own success or failure in school. At the other extreme is the idea, often linked to Piaget, of the child as natural-born scientist, building a knowledge of the world through acting on it and trying to make sense of the results (e.g., Isaacs, 1930). In between is the Vygotskian notion of child and adult engaged in joint activities in a zone of proximal development, with the child functioning as an agent insofar as the activities are concerned but with knowledge being an emergent of the social interaction between the child and a more knowledgeable other (e.g., Newman, Griffin, & Cole, 1989). These conceptions relate to quite different teaching models.

Our joint educational efforts over the past 15 years have been concerned with giving children more active roles in school learning. In general, we have adopted the prevailing constructivist view but with a special concern for the kinds of competence that are needed if children are to function successfully as agents in their own education. As a result, we have not been wholly satisfied with any of the three views just described-the behavioral view and the views typically linked to Piaget and to Vygotsky. (Note that our concern is with contemporary educational approaches, not with the theories of Piaget and Vygotsky per se or with how validly contemporary approaches reflect those theories.) In this article we focus on one particular aspect of knowledge construction that will bring what we see as fundamental educational problems into focus. This is the construction of questions to guide inquiry.

The immediate focus of our work is development of a computer environment called CSILE. The system is described more fully later. Briefly, CSILE is a networked system that gives students simultaneous access to a database that is composed of text and graphical notes that the students produce themselves and a means of searching and commenting on one another's contributions. The educational approach represented in CSILE is perhaps better understood by relating it to more general models of teaching. Elsewhere we (Bereiter & Scardamalia, 1987a) described three idealized models of teaching. The Teacher A model is a task model. The emphasis is on doing work, with learning assumed as a by-product. Teacher A's role is that of supervisor who oversees the quantity and quality of work done by the students. Although this model most obviously fits the traditional seatwork-oriented classroom, it also fits more open classrooms, so long as their emphasis is on activities rather than on knowledge. Studies of teachers who espouse a process approach to science learning, for instance, indicate that they tend to believe that activities such as collecting seeds, growing plants, or playing with laboratory equipment automatically result in learning, without concern for the cognitive processes involved in the activities. Much educational software lends itself to this activity approach -not only conventional courseware and educational games, but also text processing and graphics software, when it is used simply as a medium for activities.

The *Teacher B* model is a knowledge-based model. The focus tends to be on understanding, and the teacher's role includes setting cognitive goals, activating prior knowledge, asking stimulating and leading questions, directing inquiry, and monitoring comprehension. We take this to be the prevailing model of how teaching should be carried out. It is reflected in most of the curriculum guidelines and teachers' manuals we have seen, and it appears in analyses of exemplary teaching (e.g., Collins & Stevens, 1982; Newman et al., 1989). Knowledge-based intelligent tutoring systems also reflect this model (cf. Polson & Richardson, 1988). Although the active cognitive engagement of students figures prominently in this model, most of the high-level control of the learning process remains with the teacher or the program. Teacher B tries to be responsive to the knowledge, the interests, and the knowledge needs of students but by this very effort retains control of the educational process.

The *Teacher C* model incorporates everything that the Teacher B model includes but is distinguished by an effort to turn over to students the high-level processes that remain under Teacher B's control. Thus, there is a concern with helping students to formulate their own goals, do their own activating of prior knowledge, ask their own questions, direct their own inquiry, and do their own monitoring of comprehension. This model is seen explicitly in reciprocal teaching (Brown & Palincsar, 1989; Palincsar & Brown, 1984) and in procedural facilitation, as applied to writing (Scardamalia, Bereiter, & Steinbach, 1984). *Open Court Reading and Writing* (Bereiter et al., 1989) represented a first attempt to implement Teacher C principles in a commercial program. A number of educational software developments, including LOGO, Boxer, and CSILE, have been conceived in the spirit of a Teacher C model. It is in the nature of such software, however, that it cannot compel the adoption of a certain approach to teaching, and so one may find Teacher C-type software used in a Teacher B or even a Teacher A manner. Consequently, there is a concern with developing supportive curriculum and teaching methods. The focus of this article, on students' ability to formulate questions to guide their own study, reflects this broader curricular concern.

These three models of teaching seem to map directly on to the three views of constructivism and agency described earlier, although there is a problem with the Teacher C model. In the Teacher A model, knowledge construction is thoroughly confounded with the doing of good work. No distinction is made, for instance, between writing a good essay and making progress in learning to write good essays. Consequently, the student's role as agent is adequately encompassed by the student's role as worker or doer, and so the behaviorist conception of agency suffices. The Teacher B model fits closely with most descriptions we have seen of teaching from a Vygotskian perspective: Student and teacher are seen as engaged in a joint activity, but the teacher's understanding of the educational point of the activity is what provides direction to it. As Newman et al. (1989) put it: "It appears that this process in which a teacher appropriates something a child does, interpreting it in terms of her own frame of reference, is a means by which cognitive change can take place" (p. 13). Finally, the Teacher C model seems to relate most directly to the Piagetian view of the child as solitary experimenter and sense maker. But here the problem arises. This view (which was never held in such strong form by Piaget in the first place) is unrealistic and encourages a naive faith in the ability of children to go it alone.

There is a danger, in connection with the Teacher C model, of romanticizing the idea of the child as independent knowledge builder. Regardless of how instruction is managed, a large part of learning inevitably comes from authoritative sources -if not from the teacher, then from books, television programs, and the like. When successful learning from experimentation and analysis does occur, it generally depends on more rather than less intense involvement of the teacher than is required for didactic instruction. This is shown in Lampert's (1986) careful leading of children into working out multiplication procedures and in the Socratic teaching incidents analyzed by Collins and Stevens (1982). When teachers fail to provide direction, hands-on activities tend to degenerate into the kind that Roth (1988) found typical of process approaches to science instruction: An experiment in light and shadow degenerates into the children's making shadow rabbits and an experiment in plant nutrition leads a student to report, "I already knew that plants need light to grow and now I know it again."

If the Teacher C model is taken to deny such sobering truths, then it is a fantasy model. But in saying that the Teacher C model incorporates everything that is in the Teacher B model, we imply that it recognizes the role of authoritative information and of teacher guidance and of social construction of knowledge but yet aims to give children a higher level of agency in the knowledge-building process. This higher level of agency may be understood in terms of the Vygotskian zone of proximal development. The difference between the Teacher B and Teacher C models becomes, in these terms, a difference in the control structure of activities in the zone of proximal development,

WHO IS IN CHARGE OF THE ZONE OF PROXIMAL DEVELOPMENT?

The prototypic example of a zone of proximal development is mother and child collaborating in some activity like building a house of blocks, which is too complex for the child to handle alone but in which the child can participate fully, gradually acquiring the knowledge and skills required to carry on alone. Two kinds of development need to be taken into account when considering what goes on in the zone of proximal development. First is growth in the competencies directly involved in the focal activity (building the block house, preparing the stringbeans, reading the storybook, etc.). Here it is fitting to speak, as Vygotskians do, of children's "growing into" an activity. Second is growth toward children's takeover of executive functions - what amounts to control of the zone of proximal development itself. Here it is more a matter of children's "growing out of" their dependent status. A great deal of attention has been focused on the first kind of growth, much less on the second. The Teacher B model emphasizes "growing into" more mature competence; the Teacher C model adds a deliberate effort to promote "growing out of' dependency.

What growing out of means may be seen by comparing the prototypic example of mother-child interaction with learning as it occurs in adults. Each of us undoubtedly has a zone of proximal development. Between the zone of what we can already do and the range of things so far beyond our present competence that it would be foolish to attempt them lies a zone of things that we could profitably work to master. When working in this zone, we-like the child-can often profit from the involvement of a more knowledgeable other person. But there is an important difference, which can be brought into focus by the question, Who is in charge of the zone of proximal development?

Much of what we learn as adults is through interaction with peers, where the zone of proximal development is defined by activities the participants can handle cooperatively better than they can alone. In such cases, control of the zone is mutual. When we seek the help of someone more knowledgeable, it is usually on our own terms. Although dependent on the other's competence, we retain the regulating role. We know what we want. We know what deficiencies in our own competence the other person is supposed to fill and what we hope to gain from their involvement. We resent it if the more knowledgeable person tries to assume a larger role than we intended. We question the maturity of adults who surrender control of their zones of proximal development to a mentor or cult leader. But with children such surrender is taken for granted. In the prototypic mother-child interaction, it is the mother who decides. She sets the terms of the child's involvement in an activity, determines how much help to provide, when to begin withdrawing it. More fundamentally, she controls the purpose of the shared activity.

The shift from child to adult status, then, is a shift in executive control of the cognitive interaction in the zone of proximal development-from control by the more knowledgeable person to mutual control or control by the learner. As Diaz (1990) put it:

> The origins of self-regulation can be described as the child's gradual takeover of the adult regulating role within the zone of proximal development. The executive self emerges as children begin to do for themselves what caregivers do for them within the zone of proximal development. (p. 4)

The challenge for the Teacher C model is to facilitate this takeover of the adult regulating role in a way that does not impede and that, if possible, enhances the overall growth of children's competence.

BACKGROUND OF CSILE

CSILE grew out of earlier research on writing processes and on intentional learning. Both in writing and in learning from text, we found evidence that more expert students engage in a kind of dialectical process that enhances their knowledge and understanding (Scardamalia & Bereiter, 1985, in press). In learning from reading, the dialectic may be thought of as taking place between construction of the *textbase* and construction of the *situation model*; in van Dijk and Kintsch's (1983) terms-that is, between representing what the text says and representing the world, as referred to by the text. When given a text passage asserting that germs are not really trying to harm us, less able readers might accept or reject the statement, ignore it, or even miscomprehend it, whereas more able readers would recognize and try to deal with the disparity between this assertion and what they normally thought-for instance: "That's hard to believe. Let's see. Then I always thought [of] germs moving around or fighting with us. I didn't think that they would just settle down and raise a family. That's not exactly my idea of a germ" (Bereiter & Scardamalia, 1989, p. 375).

In writing, the dialectic can be represented as taking place between two problem spaces-a *content space*, in which problems of knowledge and belief are worked out, and a *rhetorical space*, in which problems of presentation are dealt with. By translating problems arising in one space into problems to be solved in the other, both the writer's understanding and the emerging composition are enhanced. Less skilled writers, however, do not usually exhibit this knowledge-transforming approach but instead gave evidence of a knowledge-telling process, in which knowledge is little influenced by its translation into text (Bereiter & Scardamalia, 1987b).

The original intent of CSILE, and the reason it was called an *intentional learning* environment, was to provide computer supports for this dialectical process. In an earlier classroom instructional experiment in writing (Scardamalia et al., 1984), we obtained encouraging gains in planfulness and reflectivity by providing children with procedural supports in the form of sentence openers reflecting the kinds of thinking skilled writers had been observed to do in planning (e.g., "This isn't very convincing because . . . ," "My own feelings about this are...," and "No one will have thought of...."). The experimenter demonstrated planning aloud using these supports and individual children then volunteered to do so, with their planning processes (rather than the outcomes) becoming a focus of class discussion. The two principles illustrated here that we sought to generalize through CSILE were (a) providing external supports for higher level cognitive processes and (b) making metacognitive activity, which is normally hidden and private, overt and a subject for public consideration. This attention to both the private and the public aspects of cognitive activity remains characteristic.

The public aspect of knowledge-building centers on a student-generated community database, which is CSILE's most distinctive feature (Scardamalia, Bereiter, McLean, Swallow, & Woodruff, 1989). The database is accessed via networked microcomputers (currently, eight per classroom). At the beginning of the year, the database is empty. Text and graphical notes in all curriculum areas go into the same database, where they can be retrieved by pseudo-natural language searches involving topics, keywords, authors, thinking types, and status. These last two note attributes illustrate the twin concerns of encouraging higher level processes and making knowledge-construction public:

• Thinking types. Notes are labeled, using student-designed icons, as *high-level questions, new learning, plans*, and *what I know*. (The list changes as curriculum emphases shift.) These icons are displayed along the left side of Figure 1, which shows a typical screen on which a student is reading one of a retrieved set of notes and is creating a related note. Teachers work thinking types into class assignments in various ways. One unit, on human biology, began by having students produce what I know and high-level question notes; then, after class discussions, students, individually or in teams, produced plans for how

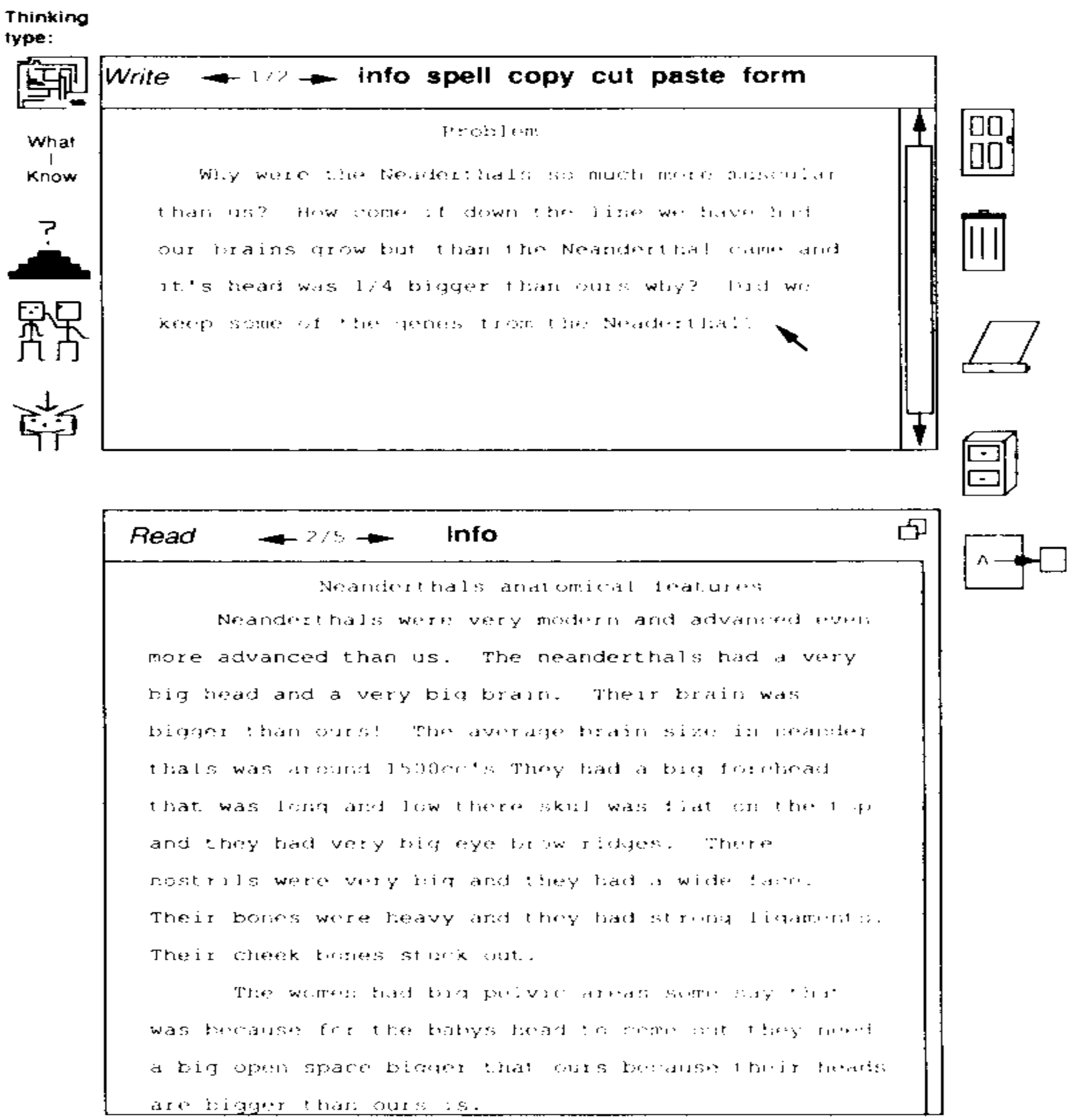


FIGURE 1 CSILE screen showing read-a-note and write-a-note windows. Arrows in read-a-note window permit stepping through a set of notes retrieved through pseudo-natural language Boolean search. Arrows on write-a-note window permit stepping through a set of notes in process.

they were going to pursue some of their questions; they then proceeded with study of the unit, using a variety of library materials and entering new learning notes to report and share what they had found out. Table 1 gives examples of notes produced by a child in a Grade 6 class at each stage of this sequence.

• Note status. Students have a choice of several different statuses for their notes. Private notes are not accessible to other students. Public anonymous and public named notes make up the bulk of the community database. However, students may also designate a note as candidate for publication. This means they believe the note to make some distinctive contribution to the knowledge base. Candidate notes are reviewed by peer committees or the teacher, may be returned for revision; if accepted, they become "published" and have a distinctive appearance on the screen. Students searching for notes on a topic may limit their search to published notes. Publishing, thus, is intended to play the role in classroom knowledge building that it plays in the learned disciplines.

Originally it had been intended that each thinking type should have procedural supports like those illustrated for composition planning-

TABLE 1

Notes by a Grade 6 Student Illustrating Four Thinking Types

I know

I know that Charles Darwin developed the theory of evolution by natural selection.
Darwin could not explain how the parents gave their characteristics to their children, or why the features sometimes changed. Modern scientists can answer these questions with the study of genetics.

Defects in the appearance of the body are also mainly controlled by genes.

High-level questions

1. What are genes?
2. How do genes work?
3. How do genes control defects in birth?
4. What were some of the theories, old and new, about the genetic code controlling appearance?

Plan

I will read parts of two books on genes. Take notes and use them to make my draft copy. I will then talk about it with my dad and find how I can change it in any way. After I have made all the changes, I will fix the spelling. Then fix the spelling again and hand in the note.

Problem

I will be focusing on the genetic code. I will try and find information on the following problems:

Why do genes determine defects in appearance? How do gene defects occur? What are the most common gene defects? Are we immune to some defects, and if so does this immune system ever break down to cause defects.

specific cues or sentence openers to aid in carrying out higher level processes. Procedural facilitations, however, must grow out of diagnosis, however. The idea is not to decide in advance how a process should be carried out and then contrive to get children to do it that way. Rather, the idea is to watch for situations in which learners appear to be blocked from achieving their goals - possibly because their goals are too vague or because their procedural repertoires are too limited or because the task is too complex - and then design relevant aids to help them over the impasse. In the case of children's commenting on each other's CSILE notes, a clear need for procedural support emerged. Children seemed generally to have the intention of writing friendly and helpful comments, but a very limited repertoire of means to do so. As illustrated at the top of Table 2, comments usually consisted of very general evaluative statements along with specific suggestions about spelling or grammar. In collaboration with teachers at the relevant grade levels, we developed sets of constructive commenting cues in the form of sentence openers such as "A reference I thought you might find useful is . . . ," "One thing I didn't understand is . . . ," "I'd find it helpful if I knew...." When teachers began to discuss commenting and to encourage use of a greater variety of content, the result was a considerable increase in the range and helpfulness of comments, as illustrated at the bottom of Table 2.

With respect to thinking types, however, we did not find the expectedc lear-cut need for procedural facilitations. The quality of questions, plans,and expositions of facts and ideas would vary greatly, depending on the activity context. What seemed to be crucial was a context in which these kinds of thinking took on significance. In the next sections of this article we report evidence showing just how sensitive children's question asking is to differences in context. In a later section we broaden the discussion to include examples of constructive commenting and the planning of inquiry, which also attest to the ability of children to perform at high levels when conditions encourage it. The point is to show that a computer-based knowledge medium can help to create such conditions. We still believe that procedural facilitations will prove helpful in enabling students to formulate more effective questions, plans, and ideas, but we are proceeding very cautiously with them, so as not to introduce procedures that have the effect

TABLE 2
Examples of Comments by Grade 5-6 Students Before and After Introduction of Procedural Supports and Teacher Encouragement

Before

Regarding your story about "The Roller Coaster" (which is spelled correctly; although throughout the story roller is spelled rollar). I think it's great. Just improve the dialogue by (and this goes to all stories) making a paragraph for each person talking. It'll make it less confusing.

Spelling Mistakes:

Kichen (spelled kitchen)
sudenly (spelled suddenly)
stoul (spelled stool)
slipery (spelled slippery)
suce (spelled sauce)
klimbed (spelled climbed)
cince (spelled since)

Jamie Coultart (spelled correctly, but with your spelling it soon won't be)

I like you story it's very strange in a way because of the part about using the swimmers legs as toothpicks. But sorry to say I found numerous spelling mistakes such as toothpicks is one word and before is spelled wrong but over all I would rate this story a 7/10. Not bad.

You made some mistakes. Check your first mom word and your first yes word and the sentence beside your first yes word.

Your note is ok but you stel have a cuppl of misstaks

After

This is a very good note, I really like the way you word it. But what I'd really like to know is what causes the diaphragm to paralyze? Maybe you could talk about what happens when it paralyzes and you could even do a chart showing it, (if you haven't already). Other than those few suggestion your note is great!

What do you mean by evolution of the bone? Your problem may not be a problem at all. How ever your problem could be proving that there was an evolution of the bone.

Some people (including myself) do not know what the third or fourth interglacial periods are, so I suggest that you explain what they are. I think you should give the average human brain capacity (which is 1400

> cubic centimeters) for a better comparison of theNeanderthals body. You might want explain what a "ceremonial burial" is. By the way, putting your information into paragraphs would make it easier for your reader to follow what you are saying.
>
> Your note is very good. I dissagree with the part that you said that the Neanderthals were the best hunters ever to exsist on the Earth I did a project on Neanderthals also so I know that practically everything you said was true you must have spent a long time researching well done.
>
> I'm rewriting this comment because CSILE erased it. It probobly won't be as good. The description in your note is very extremely good. (I mean it!!) It is good because you are very detailed, and that gives me a better idea of how the Neanderthals looked. It is also good since you tell stuff about all different aspects of Neanderthals. Some people might not know what ligaments are (maybe!?!) so tell that in your note. Well I certainly didn't know Neanderthals had a bigger brain than us! Well here's one thing I wonder about. If Neanderthals had a bigger brain. I assume they were smarter. I think we stayed on and populated the whole earth because we were very advanced so we could survive. If Neanderthals were more advanced and had a bigger brain, I don't see why they didn't just takeover the world. We'd all be Neanderthals now, if you know what I mean. I am very curious about this, do you know anything about it? I think other people would be interested too. Try to find out about this. I know it's only on anatomical features. Altogether, a really good note. Oh yeah!! pretty good keywords.
> P.S. Hit the deck!!
> Also. I think it's great that you're doing a note on all of the different early peoples' features.

of producing conformity to routines rather than greater autonomy. A great deal of work remains to be done first on overall design of the medium and on structuring its use within the classroom context before it is clear what the various procedural problems are that children need particular supports in order to overcome.[1]

[1]In doctoral research currently in progress by Irene Rukavina, supports for "reading like a scientist" are proving to have significant effects in getting children to read science texts in ways that promote conceptual change and problem solving. The need for this kind of support only becomes clear, however, when children have become sufficiently confident in knowledge building that they start making presumptuous judgments about the validity or relevance of what they are reading.

THE ROLE OF QUESTION ASKING IN CLASSROOMS

We are focusing on question asking in this article because, as traditionally carried out in schools, it epitomizes the teacher's control over the zone of proximal development and the unidirectional flow of information. Teachers ask the questions, thereby determining the goals of learning activities, and they evaluate the answers, thereby determining what is to be accepted as knowledge (Sinclair & Coulthard, 1975). By asking only questions to which they already know the answers, teachers insure that the zone of proximal development is circumscribed by their own knowledge, thus solidifying their executive control over it. Shifting the question-asking role to the students has the potential for radically altering control over the zone of proximal development. But such a shift entails several problems, which are our focus in the remainder of this article. Students' question asking can itself be managed in such a way that control of the zone of proximal development remains largely in the teacher's hands. Turning question asking into a tool for the students rather than a tool for the teachers requires care, but we hope to show that it can be done.

In keeping with our central theme, we may ask what kind of zone of proximal development exists for students when they are engaged in responding to teachers' questions. A common kind of teacher questioning is about information in texts. There are text-explicit questions, which can be answered with information taken verbatim from the text, and text-implicit questions, which require inference, often involving premises drawn from outside the text (Pearson, Hansen, & Gordon, 1979). In this situation, a zone of proximal development of some kind obviously exists, with teacher and students jointly engaged in establishing the meaning and significance of a text. As Heap (1985) showed, there is help from the teacher in forming answers and developing inferences, as a result of which children may be expected to "grow into" these competencies. But that is not all there is to learning from text. There is also determining what is important enough that it should be remembered and what inferences need to be made in order to make sense of the text or improve one's world knowledge on the basis of it. This higher order work has all been done by the teacher (or the curriculum writer) in the process of formulating the questions. There is no zone of proximal development with respect to these higher order issues of significance. The typical question-answer discourse of schooling provides no means for the child to grow into the competencies that underlie the asking of good questions. And these include competencies that are integral to learning from text.

Reciprocal teaching (Brown & Palincsar, 1989), by contrast, creates a zone of proximal development in which children can grow into the asking of text-based questions. One of the functions of the teacher in reciprocal teaching is to help children formulate questions and to upgrade the quality of their questions, so that they deal with issues of increasing significance to text understanding. Reciprocal teaching perhaps contrasts most strikingly with conventional teaching in the nature of the activity toward which progress is aimed. In conventional question-answer teaching the implicit target is a question period in which the students all give accurate and thoughtful answers to the teacher's questions. (Teachers will, of course, have goals beyond this, but they would have to be realized in some other activity.) In reciprocal teaching the target activity is a thoughtful discussion that the students carry on by themselves, having gradually weaned themselves from dependence on the teacher to direct the discussion and to help them perform their roles in the discussion. It fits the Vygotskian model in that the children grow into an activity that has meaning for them in its own right and at the same time grow out of the need for external support in the activity.

The case we have been considering is one in which the starting point is a particular text and the task is to extract meaning from it. A more complex but also more inclusive case is that in which the starting point is a state of knowledge and the problem is to advance that state. This is the generic case, not only of subject matter learning in schools but of knowledge building and scholarly inquiry. The knowledge-building case, as we call it, raises several difficulties that are not present in the case of learning from a specified text. Can children recognize what they need to know? Can they formulate questions that will advance their knowledge? Can they sustain inquiry? It would appear that much more is required in order for children to take over executive control of their zones of proximal development in the knowledge-building case.

Miyake and Norman's (1979) work on question asking raised doubts about the ability of naive learners to recognize their own knowledge needs. They concluded, "a theory of questioning that suggests that people ask questions to fill in their knowledge structures is too simplistic. People do not appear to be able to cope with material too far beyond their present knowledge" (p. 362).

The kinds of questioning that skilled Socratic teachers use to help students advance their understanding do, indeed, seem to lie beyond the abilities that could be expected of young students. Collins and Stevens (1982) found the questions of skilled inquiry teachers to perform functions such as the following:

- Ask for sufficient factors.
- Ask for similarities in factors between similar cases.
- Ask for the formulation of an alternative rule.
- Ask for predictions using hypothetical cases based on irrelevant or insufficient factors.
- Ask questions that trap students into revealing their misconceptions.
- Ask series of questions that lead students into a contradiction.

Their analysis also showed expert teachers to use a variety of sophisticated strategies for selecting cases to raise questions about. It appeared that the expert teachers tailor cases to the student's zone of proximal development, selecting paradigm cases early in learning, followed by cases that require the students to refine their generalization and differentiations and to deal with variability. Collins and Stevens acknowledged that this kind of teaching requires both substantial skill and knowledge of the subject matter. Yet this is the kind of inquiry that shifts schooling from learning what is in the text to learning to understand the world, using information from texts and other sources. If this kind of question-based teaching is too difficult for many teachers, what chance have students to take over control of their own zones of proximal development in knowledge building? In significant part, their chances will depend on the kinds of questions they are able to raise, and it is this issue that we discuss next.

We conclude this section by reviewing what it has indicated concerning giving children executive control in their zones of proximal development.
We have seen that question asking is a means by which teachers retain control over the zone of proximal development. As Dillon (1982) put it: "The dynamics of a question-answer relationship establish respondents in a passive, reactive role, fostering dependency and removing a sense of responsibility, initiative, and a kind of energy" (p. 160). Letting the children ask the questions might therefore seem to be an obvious way of giving them ownership over their zones of proximal development. However, to speak of "turning the question-asking role over to students"-as if it were on a par with reallocating responsibility for taking attendance-is an oversimplification so extreme as to be dangerous. From the preceding discussion, several reasons stand out:

1. The structure of question-asking discourse is an integral part of the overall structure by which teachers maintain control in classrooms. Even if teachers were willing to relinquish control, the control structure cannot simply be inverted. You cannot flip from having one teacher in control to having 30 children in control; some quite different social structure must accompany a change in the question-asking role.

2. Questions asked by teachers have a special character that distinguishes them from the kinds of questions people normally ask. One would not necessarily want children to ask the kinds of questions teachers ask.

3. Question asking by teachers presupposes knowledge of the domain under study; question asking by students must presuppose the opposite.

4. Besides domain-specific knowledge, question asking by teachers requires sophisticated metacognitive knowledge and skills. Typical question asking dialogue in schools provides no way for students to develop this metacognitive layer of competence. Some other means must be found to advance students' ability to carry out the metacognitive functions that underlie skillful question asking.

Giving children a higher level of agency in their zones of proximal development would therefore require not just opening the classroom to students' questions but providing a new structure that supports children in growing into a question-asking role. It must also be a structure within which children's questions are instrumental in their knowledge development.

CAN CHILDREN ASK EDUCATIONALLY PRODUCTIVE QUESTIONS?

Previously, we drew a distinction between asking questions based on text and asking questions based on perceived knowledge needs. We take the research on reciprocal teaching (Brown & Palincsar, 1989; Palincsar, 1986) as evidence that children can, with the appropriate scaffolding, successfully take over the asking of text-based questions. The question to be addressed in this section is what children's prospects are for taking over the asking of knowledge-building questions.

We do not mean to argue for a fundamental distinction between the two kinds of questions. Both kinds could occur in reading or discussing a text. This is made explicit in the comprehension model of van Dijk and Kintsch (1983) and Kintsch (1988), which conceives of two related representations constructed during reading - a text base, which is a semantic representation of what the text says, and a situation model, which represents the world as it relates to the text. However, findings by Mannes and Kintsch (1987) indicated that deeper processing is required to produce an adequate situation model than to produce an adequate textbase. When readers were provided an outline in advance that paralleled the organization of the text, this aided their development of a textbase adequate for recall but impeded their development of a representation adequate for problem solving, in comparison to a condition in which the organization of the outline varied from that of the text, so that deeper processing of content was required. What we call text-based questions here are the kinds of questions (including questions about the world) cued by a textbase. What we call knowledge-building questions are ones that arise from efforts to construct a situation model .

Any question asking may be assumed to involve both botom-up and top-down processes. There is likely to have been something seen, heard, or read that cues questioning in a bottom-up manner, although prior knowledge and beliefs provide top-down constraints on production of the question. We would expect bottom-up processes to be more salient with text-based questions, however, and top-down processes to be more salient with knowledge-building questions. In the extreme case, a knowledge-building question might arise from pure reflection, with no external stimulus at all. The extreme case on the other end would be a text-based question that involves merely linguistic operations on a text statement-converting a declarative to an interrogative sentence without any necessary use of world knowledge (e.g., Text: "The action of serotonin is blocked by LSD." Question: "What is blocked by LSD?").

In elementary school classes that we work with in connection with the development of CSILE, it is a common practice for students to generate their own questions at the beginning of a unit of study. Typically, these questions are produced after some introductory lessons, videotapes, or browsing of reference material, and the questions are intended to serve as goals for further study. That is, students are expected to go out and seek answers to the questions, entering their findings into the CSILE database. This procedure has worked well both at the metacognitive level of developing in students a better conception of what there is to be learned and at the level of learning outcomes: greater depth of explanation when students report what they have learned (Scardamalia, Bereiter, Brett et al., 1989). We noticed, however, that the questions produced seemed to be of a lower order than the ones discussed in the preceding section. Students appeared to ask questions to which the answers could be found in the material they had already been exposed to. When students generated questions in a context of free speculation, without prior study, knowledge-building questions seemed to be much more in evidence.

These observations were rendered questionable, however, because differences in the conditions under which questions were produced were confounded with differences in topic. We therefore decided to collect some more systematic data by getting students to produce questions on the same topic but under different conditions. (A full report is available in Scardamalia & Bereiter, 1990.)

QUESTIONS PRODUCED UNDER TEXT-BASED AND KNOWLEDGE-BASED CONDITIONS

One CSILE installation involves two combined Grade 5-6 classes in an inner city elementary school serving an ethnically and socioeconomically heterogeneous population, with a higher-than-average representation of children from educationally advantaged homes, but also including a substantial number of recent immigrants and children considered to be at risk. Assignment of students to the two classes is reportedly random. One of these classes did a unit on the topic of "endangered species," in the course of which 20 contributors produced a total of 104 questions. The students selected reference materials and perused them before generating questions, and the questions were intended to guide their further study. This constitutes what we call the text-based condition.

In the other Grade 5-6 class, we simply introduced the topic of endangered species without preliminaries, and asked the students to write questions reflecting what they wondered about or needed to know to advance their understanding of endangered species. They were told that they should not concern themselves with whether they could answer the question-it was fine if the question was so hard that it would challenge experts in the field. They had no access to reference material and simply wrote their questions on a piece of paper. This was what we call the knowledge-based condition, because the students' prior knowledge was the only basis on which their questions could be formed.

Under the knowledge-based condition, 28 students produced a total of 150 questions. One difference between these questions and those produced under the text-based condition was immediately evident. Many of them (45%) reflected political or social concerns, for example: "Could we teach our children not to be so cruel with all the people around them being so cruel?" "Why must we choose forests and countrysides to build more and more cities? Don't we have enough?" No such questions appeared in the text-based condition. Assuming that the same amount of environmentalist concern was present in both classes, it is interesting that in the text-based condition none of this was activated.

In further comparisons of the students' questions, we set aside the political/social ones and included the remaining 82 questions from the knowledge-based condition which, like the questions from the text-based condition, dealt with knowledge about endangered species rather than with endangered species as a problem to be dealt with. The sets of questions generated under the two conditions were randomly intermixed, along with 6 representative questions drawn from published curriculum materials, and were rated by graduate students according to how much pursuit of the question could be expected to contribute to learning. Table 3 gives examples of questions at each of 4 rating scale levels. Questions from the knowledge-based condition averaged significantly higher than those from the text-based condition, with a mean of 2.52 versus a mean of 1.58. The published curriculum material questions fell in the middle, with a mean of 1.75. Further ratings, based on a subset of the questions, indicated that questions

TABLE 3
Examples of Questions at Four Levels on Knowledge-Advance Scale

Level 1
- Are there any white rhinos left?
- Are panda bears an endangered species?

Level 2
- What is the most endangered species?
- Why are condors an endangered species?

Level 3
- Are all these endangered species in all the poor countries? If so. why?
- Is it because of our carelessness that many animals are becoming endangered? What is the main reason?

Level 4
- If a meteorite hits the world, and everything dies. how can more life evolve again from amoebas and things? Why wouldn't they get blown up too?
- When an animal is endangered, how does it make a comeback?

produced in the knowledge-based condition were also significantly higher in (a) the complexity of search required to answer the question, (b) how interesting the question was to the rater, and (c) the extent to which the question called for an explanation as opposed to a simple factual response.

More important than mean item quality, however, is the actual number of items generated in a class that are judged to be educationally worthwhile as guides to study and inquiry. In the text-based condition, 4 of the original set of 104 questions (4%) were rated 3 or higher, indicating a judgment that obtaining an answer to the question would produce "an advance in conceptual understanding." By contrast, 38 questions (46%) produced in the knowledge-based condition were rated at this level.

These results show a strong advantage for the knowledge-based condition over the text-based condition. Note, however, that the two conditions differed in several ways, so that it is impossible to isolate a causal factor. We do not know, for instance, what would happen if students were given prior exposure to material, as in the text-based condition but were urged to reflect on their own wonderings and needs to know. We suspect that the factors interact: that, especially for young students, recent information is likely to have a potent effect on what comes to their minds, regardless of instructions, and that students will inevitably censor their questions de-pending on what they expect to be the consequences of asking them. If students are to be held accountable in some way for seeking answers to the questions they ask, it is to be expected that they will adopt strategies to minimize risks of failure or overwork. It is nevertheless noteworthy that under the knowledge-based condition, encouraged to give free rein to their curiosity, one class of elementary school students produced a total of 38 questions (in addition to those expressing sociopolitical concerns) judged to be of substantial educational value- surely enough questions to form the basis of a worthwhile unit of study, provided a way could be found to identify and make use of those questions.

BASIC QUESTIONS AND WONDERMENT QUESTIONS

On the topic of endangered species, used in the preceding study, children seemed to have enough prior knowledge to begin asking worthwhile questions. Although they lacked much specific information and may have had misconceptions (e.g., believing that slaughter by humans was the main cause of endangerment), they at least had a general idea of what it meant for a species to be endangered and of the social importance of the topic. How well would question-asking fare on a less familiar topic?

To investigate this question, we had students produce questions on the topic of "fossil fuels." We chose this topic because one of the two Grade 5-6 classes previously described had done a unit on it, and the database showed a good deal of research effort devoted to basic issues such as "What are fossil fuels?" Accordingly, we had the other Grade 5-6 class generate questions on this topic without prior instruction, expecting that they would have a less adequate knowledge base to start with than had been the case with the class generating questions of endangered species.

We presented the knowledge-based question-asking task in exactly the same manner as in the previously described knowledge-based condition. Our expectations that we were dealing with a low-knowledge topic were confirmed when one student asked, "What are fossil fuels?"; large numbers of students accentuated that question with nods. We asked if anyone knew what fossil fuels were. Two students raised their hands and one volunteered the definition, "Fossil fuels are fuels that come from the ground." One child asked if oil was an example and another child said yes.

Despite this inauspicious beginning, students generated 104 questions for the topic fossil fuels-an average of 5.5 questions per student, almost exactly the same as under the comparable condition for the topic of endangered species. Lack of domain knowledge, therefore, does not seem to have hampered students in generating questions. Indications of the students' limited knowledge about fossil fuels do appear, however, in the kinds of questions asked.

More than half of the questions from the fossil fuels condition represent what we may term *basic information questions* and *uneducated guesses*. Basic information questions, of which there were 39, included the following: What are fossil fuels? What are fossil fuels made of? Why the *name fossil fuels*? What are the uses of fossil fuels? Where do fossil fuels come from? These questions have a textbased quality to them; they seem to get quite directly at the kinds of information normally conveyed in basic textbased or encyclopedia treatments of a topic. Uneducated guess questions are yes-no questions that seem to have a similar motivation to obtain basic orienting information, except that they take the form of shots in the dark at possible answers. The 18 questions of this type generally asked whether something (e.g., water, lava, chalk) was a fossil fuel or whether something (e.g., electricity or minerals) was related to fossil fuels.

The remaining 47 questions we may call wonderment questions. They reflect curiosity, puzzlement, skepticism, or a knowledge-based speculation, in contrast to a groping for basic orienting information. Examples of wonderment questions are given in the right-hand column of Table 4. Matched with them are basic information or uneducated guess questions asked by the same individuals. Thus it is evident that the two categories of

TABLE 4
Examples of Basic Information and Wonderment Questions Asked by theSame Students

	Basic Informorion questions	Wonderment Questions
Student A	Is food a fossil fuel?	Is everything either a fuel or needs a fuel?
	Are some things alive and fuels?	

Student B	Does metal have anything to do with fossil fuels?	Did the caveman know what fossil fuels were?
	Are fossil fuels found in food? plastic?	Are fossil fuels still being explored by scientists?
Student C	Do we have fossil fuels in our bodies?	Does the moon contain fossil fuels?
Student D	Is cloth a fossil fuel?	Can you make different fossil fuels by mixing other fossil fuels?
	Is steam a fossil fuel?	
	Is fire a fossil fuel? :	How long do most fossil fuels last?
Student E	Is heat a fossil fuel?	When was fuel discovered?
	Is air a fossil fuel?	
Student F	Does this fossil have to do with dinosaurs?	Does fossil fuel affect the ozone layer?
	Do you use fossil fuels when you have a barbeque?	
Student G	Does the word fossil in fossil fuels have anything to do with fossils?	What are all the things that are made of fossil fuels?
Student H	Why is it called fossil fuels?	What is the difference between fossil fuels and other types of fuels?
	What creates fossil fuels?	
		Are fossil fuels found everywhere or does it have to be a certain climate?
		Is there anything that will only run with fossil fuels?
Student I	Is lava a fossil fuel?	How does fuel energize cars, boats, planes and so on?

question are not characteristic of different kinds of students. The same students ask questions that seek basic information that will orient them to a topic and ask questions that show active thinking, in which what they already know is used to probe beyond the basics of the topic.

Basic information questions were much less evident in the endangered species set. The only recurrent question of this type was "Why are (cougars, condors, etc.) endangered?" (5 such questions appeared). No student asked the most basic question, "What is an endangered species?" Presumably they all had this basic understanding, and so were able to concentrate on wonderment questions like, "How do scientists count a species so they know when it is endangered?"

Although the less familiar topic of fossil fuels produced a majority of questions at the basic level, there were nevertheless 16 questions rated as having the potential to produce "an advance in conceptual understanding." This amounts to 15% of the questions-greater than the 4% produced on endangered species in the text-based condition, less than the 46% produced in the knowledge-based condition. All 16 of the highly rated questions were of the wonderment type.

Considering jointly the questioning carried out on the topics of fossil fuels and endangered species, it appears that the students appropriately adjust the kinds of questions they ask, according to their level of knowledge.' If they already have a basic understanding of a topic, as with endangered species, they ask questions that have potential to extend their conceptual understanding. If they lack elementary knowledge, as with fossil fuels, they ask questions of a basic "What is it? Where is it? What causes it?" type. But the asking of such essential questions does not preclude their also asking wonderment questions of a challenging and stimulating kind.

These findings thus indicate considerable potential for children to take over greater control of their zones of proximal development.

CAN STUDENTS IDENTIFY THE EDUCATIONALLY MOST VALUABLE QUESTIONS FROM AMONG THOSE THEY GENERATE?

Given that students generate more questions than they could investigate within the time normally available for a unit and that these questions vary greatly in their judged potential for aiding knowledge advancement, it becomes important to find out how successfully students can select questions to pursue. We had students (from the same classes that had generated the questions originally) rate selected questions according to how much they thought pursuing those questions would advance their knowledge. These ratings were then correlated with the comparable ratings made by experimenters.

On the topic of endangered species, where students already had some basic understanding, there was a generally high level of agreement among children and adults about what questions are of greater or lesser educational value. Combined student ratings correlated .89 with experimenter ratings of the 22 questions on this topic. The median correlation of individual student ratings with experimenter ratings was .60(n = 25 students) but with a range of -.37 to .90. For fossil fuels questions, however, the pooled-ratings correlation was only .56 over 22 questions. The median correlation for 24 students was .40 with a range of .14 to .66. In rating the fossil fuels questions, students and adults seemed to agree in identifying what we have called wonderment questions as being questions whose investigation will lead to significant conceptual advance, but in judging basic information questions, children seemed to have difficulty distinguishing naive questions that are merely ill conceived from naive questions that raise important conceptual issues. This was evident from interviews discussed in the full report of this research (Scardamalia & Bereiter, 1990).

We take these results to indicate that there is substantial educational wisdom available in a group of students, even when they do not know much about the topic whose study they are contemplating. There is an obvious problem in how this wisdom is to be marshaled. The statistically combined judgments of a group do not necessarily correspond to anything that could or should be realized in practice. What seems to be required, in order for children successfully to assume executive control in their own zones of proximal development in a classroom setting, is a social process that allows the wisest judgments to work their way forward. The beginnings of a response to that challenge are discussed next.

COOPERATIVE KNOWLEDGE BUILDING IN A COMPUTER-SUPPORTED INTENTIONAL LEARNING ENVIRONMENT

Evidence on children's questioning indicates that, even in areas where they have little prior knowledge, children can produce questions that could profitably guide inquiry and study. This evidence suggests, therefore, one kind of potential for students to assume a higher level of agency in their zones of proximal development. That this potential is seldom exploited in school curricula goes without saying. But what would it take to use children's competence in question asking effectively? The ability to ask a question does not imply the ability to find an answer to it. We have already seen evidence that when students generate questions that they expect they will have to try to answer, they sensibly opt for text-based questions whose answers they can be fairly sure they will find in the material available. These questions tend to be of a low order, inferior to questions provided in published curriculum materials. The high-order questions children ask tend to come when they are free to wonder and under no threat of having to seek answers for the questions they raise. But, then, how can students' wondering be put to use?

We do not have an explicit answer to that question. Instead, we report hopeful observations about knowledge-building activities of students in a computer-supported environment. To provide a context for these observations, it is important that students' questions be seen in a broader perspective of knowledge-building activities. There is much more to acquiring an understanding of endangered species or fossil fuels than finding the answers to a list of questions, no matter how good those questions may be. Knowledge should have a structure that makes it possible to see how one proposition or question relates to another. Furthermore, there is a time course to learning, which can make the answer to one question depend on the answers to preceding ones; new questions can be expected to emerge as inquiry proceeds, or old questions may be reinterpreted. In a cooperative learning environment, such as we are trying to achieve with CSILE, questions will ideally form part of a dialogue that moves progressively toward deeper levels of explanation.

Accordingly, the observations that follow do not represent children pursuing answers to a list of questions. Rather, they represent children engaged in cooperatively developing and extending their knowledge, within an activity structure that allows children's questions, discoveries, and ideas to interact cooperatively and to give direction to their efforts.

How Cooperative Knowledge Building is Supported in CSILE

CSILE-related research currently in progress, dealing with cooperation and group work, indicates the importance of distinguishing between the two.[3] In ordinary classrooms, because small group work presents the only practical way for students to cooperate in learning, the two are almost inevitably conflated. But with an information medium like CSILE, there are ways for students to cooperate that do not involve their working together as groups.

On a given unit, some students may work as a group, deciding which questions to pursue and assigning individual responsibilities, whereas other students may pursue their own questions independently, cooperating only through commenting on or using information from other students' notes.

Or the teacher may prescribe a way of proceeding, based on considerations of difficulty of the topic, availability of resources, and so on. It appears that children as early as the first grade understand and appreciate the value of cooperation, but by the fourth grade many students have acquired serious reservations about working in groups. They are aware of the variety of things that can go wrong: rivalries and domination, the suppression of novel ideas, time wasting, and the plain nastiness that often infects preadolescent social relations.

In CSILE, students can cooperate with one another by means of comments on one another's notes-by comments that raise questions, suggest information sources, provide constructive criticism or counter-arguments, or that simply provide praise and encouragement. In a larger sense, they can cooperate the way people who are doing related work in a scholarly discipline cooperate to advance knowledge-by paying attention to what one another has found out and by trying to extend it or go beyond it. More directly, they can work together off-line preparing material that eventually goes into CSILE as notes. It may be asked what will induce students to cooperate in these ways? Initial findings from research in progress by Earl Woodruff suggest the following:

1. Without any urging, some students spontaneously engage in a considerable amount of cooperative activity of the kinds indicated, although others do little or none of it. The commenting that occurs spontaneously appears to be generally cooperative in intent, although limited in variety.

2. Simply by introducing a cooperation icon so that students can mark notes that involve or intend cooperation and discussing the value of cognitive collaboration, a significant rise in the frequency of commenting and other cooperative efforts can be observed.

3. Further gains in quantity and quality can be obtained by discussions of ways to cooperate-by making cooperation an overt goal of classroom efforts.

Communicating through a public written medium probably in itself does much to encourage a higher level of civility. When CSILE was first introduced into classrooms nasty anonymous notes began to appear, but ceased abruptly when the students were reminded that teachers had access to authors' names. Following the example of Lampert (1988), however, we have been trying to coach children in the spirit and language of constructive commenting-going so far as to provide a menu of sentence openers, as indicated earlier.

A common problem with cooperative group work in classrooms is keeping the less able and less aggressive students from being sidelined. Woodruff’s research should show to what extent this is a problem in CSILE. One thing we do know, however, is that CSILE provides ways for less able students to participate. Learning disabled students, who would have difficulty producing original text, find that they can copy text from someone else's note or from a combination of notes and edit it to have it say what they want. We also find some less able students playing the role that Miyake (1986) found less knowledgeable pair-members playing in efforts to explain how a mechanical device worked: They prevent the premature closure of inquiry by asking questions or requesting fuller explanations.

CSILE is now undergoing major redesign to provide the additional tools and supports that 4 years of experience with the initial version suggest will help children assume higher levels of agency in their zones of proximal development. Among other things, the new version will provide continuous monitoring of many aspects of student participation, so that questions about excluded students and about the frequency of various kinds of cooperative action can be readily answered. In the observations that follow, we point out the needs for enhancement of CSILE and show what children have been able to do with the existing facility.

An Example of Cooperative Commenting

As illustrated in Figure 1, CSILE students can have "read a note" and "write a note" windows open on the same screen. This encourages students to write comments on each others' notes. The system calls comments to the attention of the author of the original note, but they are also available to anyone else who reads the original note.

Figure 2 shows connections among a set of notes and comments produced by six students working on a unit on "human evolution." Most of the notes are produced by Ted, one of the lower achieving students in the class, who studies skulls. His first note indicates nine information sources he plans to use, with the nearby Royal Ontario Museum being first on the list. A comment from Rose suggests an exhibit at the museum that deals with skulls. Ted's next note lists names and ages of hominid skeletons he has noted. There follows a note with a hypothesis about evolution: "When a baby was born 4 million years ago and it had one change of its body closer to man like standing up straighter or having a different skull shape, that could be why our ancestors changed to be us[4]" A comment by his friend, Wilf, points out the speculative nature of Ted's note, saying "The only real fact in it is that a baby was born 4 million years ago. That's not really much information." Ted subsequently produces a richly factual note and then summarizes his findings about skulls in a note that is commented on by Rog. Rog praises the note and asks six rather stimulating questions, including "Do you think that we might ever become apes again and why?" and "Why don't apes turn into humans anymore?" In the meantime, Wilf produced a note of his own, summarizing his findings on the early history of tool use. Ted comments on this note, suggesting questions that would lead to a deeper analysis of the topic: "First you could add some information like about how the neanderthals could live through the ice ages and how could they make the fire in the cold?" Unconnected with Ted and his colleagues is a note by Amelia on Homo erectus. Angie comments on this note, "I found the part about Homo erectus's appearance very interesting. That's something that not many people know about. The part you wrote about fire was also quite interesting." Angie then mentions a clipping about Peking man that she thinks Amelia might find useful.

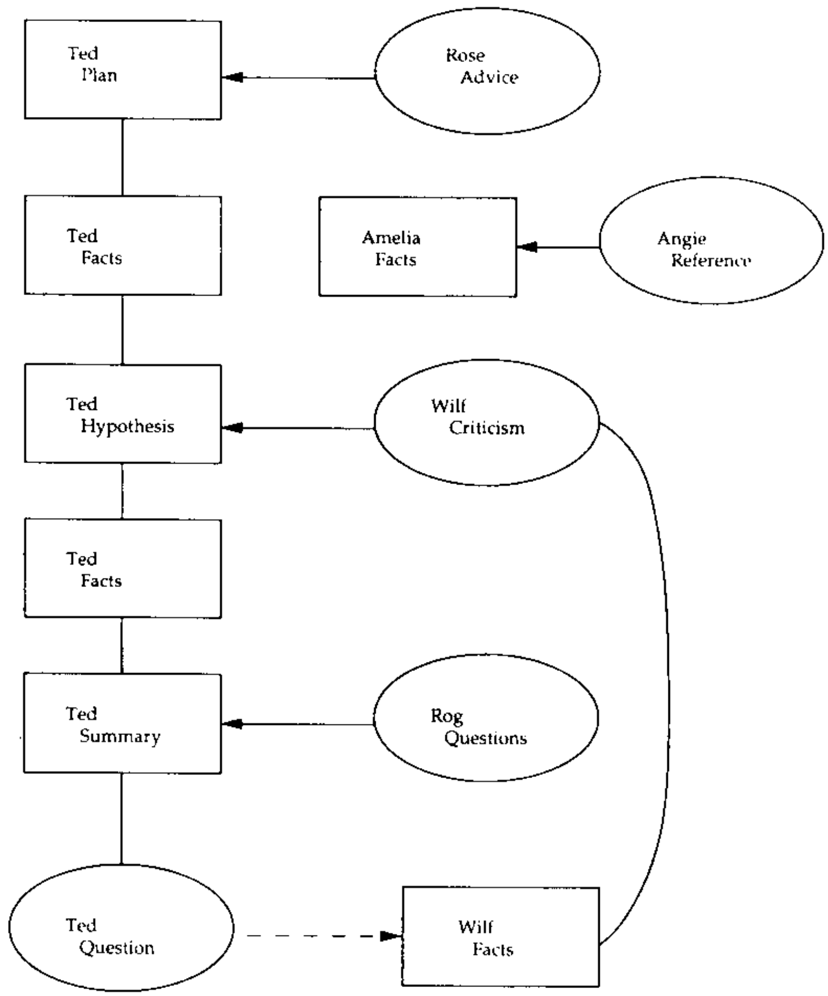


FIGURE 2 Cooperative commenting. Schematic representation of a set of related notes and comments. Rectangles represent notes; ovals represent comments. Time proceeds from top to bottom. See text for discussion of note content.

These notes and comments indicate the potential for students, even relatively low-achieving students, to assist one another and to upgrade one another's inquiry through suggestions and questions. They also indicate two needs, which we are trying to meet in the redesign of CSILE:

1. More ways to link students with common interests. It is clear to us that Amelia and Angie would have had much to contribute to the work centering around Ted and Wilf; but the students themselves were probably unaware of this. Although students can search for notes on the basis of keywords, topics, author, along with other criteria, the usefulness of such searches is limited both by the competence of authors in assigning identifiers to their notes and by

the competence of readers in delimiting a search. Students tend to rely heavily on search by author, which means that they tend to make connections with others already known to share their interests. In redesigning CSILE, two avenues are being pursued to facilitate the linking of students on thematic bases. One is the design of graphical keyword-organizing interfaces.[5] Keywords are organized into diagrams or attached as labels on scenes, and from the interface students can pull keywords to attach to their notes, retrieve other notes bearing the keyword, obtain definitions, or see a list of other keywords that have been associated with the keyword in question. Preliminary observations suggest this kind of interface greatly increases the number of keywords assigned to notes and results in fewer idiosyncratic keyword assignments. It should therefore increase the likelihood of students using keywords rather than authors as a search criterion. The other avenue is inspired by the Analog Retrieval by Constraint Satisfaction (ARCS) program of Thagard, Holyoak, Nelson, and Gochfeld (in press), which retrieves analogs. ARCS identifies potential analogs by computing semantic similarities, using an automated thesaurus. This much of ARCS should be applicable to comparison of notes. Because such comparisons are computationally intensive, our plan is to run them as overnight operations, which would present students the next day with pointers to the notes most likely to be closely relevant to notes of their own. By such a process, we would expect Ted and Wilf to be made aware of Angie's work and vice versa.

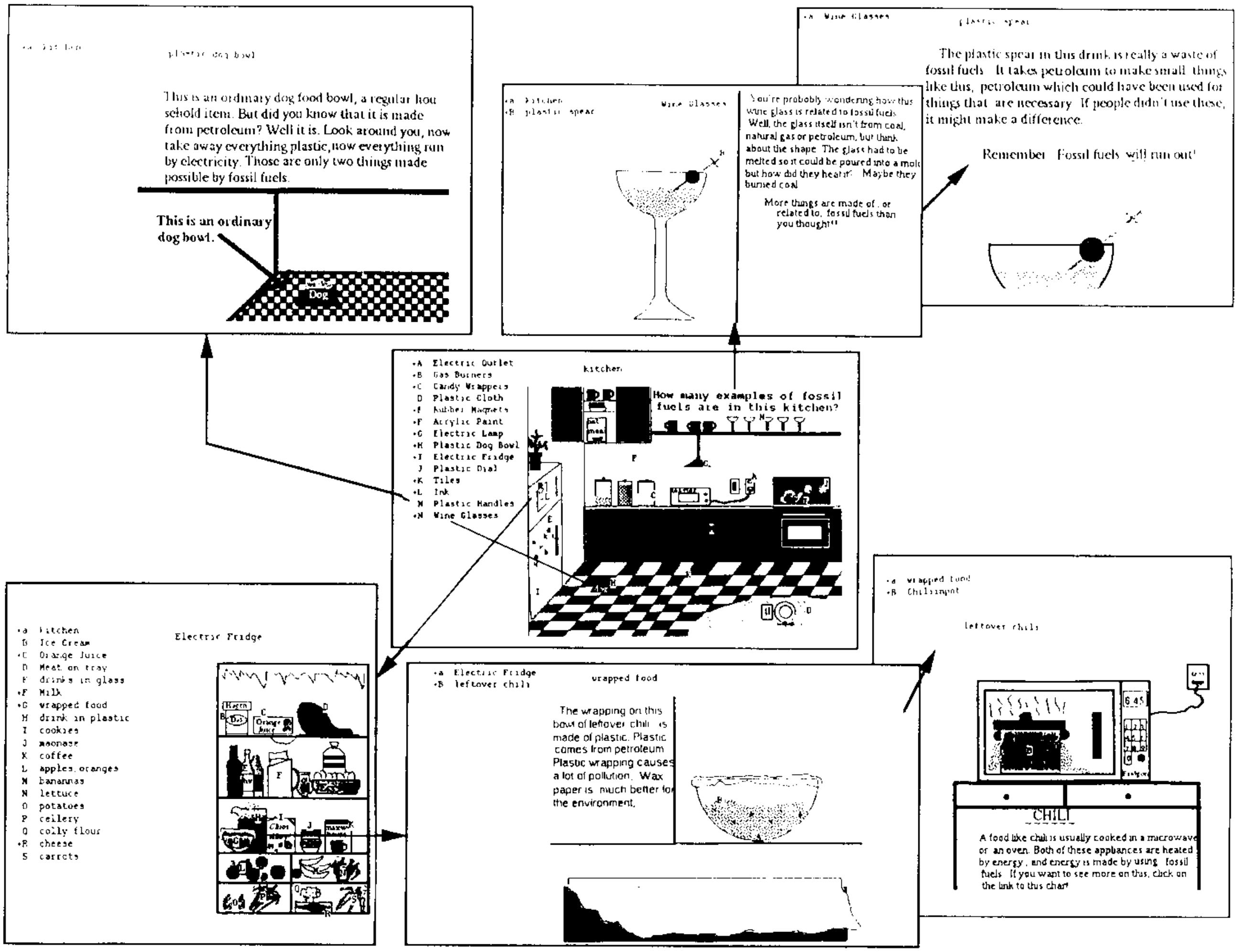
2. Support for pursuit of convergence and coherence. In the note sequence depicted in Figure 2, Rog raised several provocative questions, which, however, seem not to have been followed up. In general, we find students engaging readily in the divergent processes of knowledge building-generating questions, hypotheses, and relevant information-but needing help in the convergent processes-pruning hypotheses, weaving information together into coherent accounts, pressing beyond superficial explanations, and so on. Correspondingly, CSILE in its current version lends itself nicely to divergent processes but lacks support for convergence. Plans for the new architecture include special knowledge-building environments. One will provide tools for describing and simulating processes, specifically supporting the kind of constructive interaction that Miyake (1986) found to go on when pairs of people are trying to work out an understanding of a process. Another environment will focus on explanatory coherence, providing an interface for organizing networks of facts needing explaining and hypotheses explaining the facts, based on Thagard's (1989) computer implementation of his theory of explanatory coherence.

We expect that through these enhancements to CSILE, there will be more opportunities for the best ideas to work their way to the front and for them to be pursued to the point where they result in substantive gains in understanding.

An Example of Cooperative Elaboration

Somewhere between divergence and convergence is organized elaboration, where students assemble information within some organizing structure. Having students work to a prescribed outline is a didactic way of structuring such elaboration. The jigsaw classroom, as implemented by Brown and Campione (in press), organizes the social arrangement rather than the product, designating different knowledge to be acquired by different students, and a way for them to interact to produce products that combine and organize that knowledge. In the example that follows, organized elaboration takes place spontaneously, supported by the functionality of CSILE's *charts* program.

Charts incorporates conventional graphics software into a system that permits charts to be hierarchically linked via labels attached to the parent chart. Thus users can "zoom in" or "zoom out" through any number of levels of hierarchy, with the levels representing part-whole relationships, levels of detail, or any other relationship the students may think of. Although students cannot edit each other's charts, they can freely connect new charts to them. This provides a structure for cooperative elaboration that will tend naturally to have a hierarchical structure.



Cooperative elaboration. Students elaborate the theme of fossil fuel consumption by producing charts hierarchically descending from a parent chart (kitchen scene). Each chart (only a few examples shown) explains how fossil fuels are used in relation to the selected object. All texts and drawings are original.

Figure 3 shows a few examples from a much larger network of charts, all linked ultimately to the kitchen scene at the center of the figure. This network was originated by a group of four students working on the fossil fuels unit mentioned earlier in this article. The idea that gives coherence to the network is the challenge they set themselves, to show all the ways that fossil fuels are used in an ordinary kitchen. Thus, fuels used in plastics, in manufacturing processes, and in generating electricity to power appliances are all noted. Recall that most of the students initially had little idea what fossil fuels are. That being the case, this kind of systematic elaboration off acts about fossil fuels, their uses, and their conservation, in a realistic context, would seem to build up just the kind of basic knowledge the children showed, by their questions, that they needed. In fact, the whole project can be seen as addressing the same basic-information question that six students in the other class asked in the knowledge-based condition, “What are the uses of fossil fuels?"

An unfortunate limitation of the present version of CSILE is that the charts program and the text-notes program are only weakly linked. Text notes cannot be hierarchically linked the way charts can, and charts cannot be commented on the way text notes can. In the new version of CSILE all notes, regardless of medium, will have both capabilities.

Prospects for a Higher Level of Student Agency in Knowledge Building

We asked teachers of the children who participated in the studies described earlier to classify questions the children produced. Categories were: "I know the answer already"; "I don't know the answer off the top of my head; it is not, however, a challenging research question"; and "I could profitably be engaged along with the students in research on this question." The teachers put about half of the questions into the last category. We envision an educational model that can take advantage of this result-whole groups, including the teacher, striving to outdistance current limitations in their understanding.

There is then no question of displacing the teacher. Teachers can be vital participants in the community knowledge-building process, but they need no longer constrain it to what they comfortably know. The zone of proximal development comes to be defined by the knowledge-building activities that the group, as a collective, can profitably engage in. Individual differences, so often a grave problem in school, can fall into place naturally, if the point becomes that everyone should have something to contribute rather than that everyone should try to excel.

We think this model has not had a chance in education because the structure of the classroom has forced teachers to assume control of knowledge building, whether as didactic conveyors of information or as gentle managers of the intellectual life of the classroom. New knowledge media open up new possibilities-both for democratizing the knowledge resources available to schools and for moving knowledge building to the center of the life of the classroom community. The experience and findings reported in this article of course leave many questions unanswered. The most important probably have to do with generalizability: What would question asking be like among children less in contact with mainstream culture? How much of what we have observed with CSILE would appear with more disadvantaged students or with different kinds of teachers? Such questions obviously need to be investigated, but we would argue against a simple empiricist approach to them. We ought to assume that there is potential for a collective zone of proximal development in any classroom, and that within it there is at least some potential for the students to move toward higher levels of agency, not just higher levels of competence in performing the established tasks. The research task, therefore, is to identify that potential and to look for ways to realize it.

[2]It is difficult, of course. to compare the amount of knowledge children have in one domain and another, and especially to distinguish lack of knowledge from nonretrieval. No doubt if the topic had been presented as "oil. gas, and coal" rather than "fossil fuels," more knowledge would have been activated, resulting in different questions. Perhaps, therefore, the point should be refined to say that children adjust to their perceived level of knowledge.

[3]This research is being carried out as doctoral thesis work by Earl Woodruff (on cognitive cooperation) and Elaine Coleman (on effects of group work on problem solving and conceptual change).

[4]Spelling and punctuation have been corrected in quotations from student notes.

[5]The idea for these interfaces came from Jacques Viens, who is studying their effects in doctoral research.

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