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COGNITIVE APPRENTICESHIP: MAKING THINKING VISIBLE

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IN ANCIENT times, teaching and learning were accomplished through apprenticeship: We taught our children how to speak, grow crops, craft cabinets, or tailor clothes by showing them how and by helping them do it. Apprenticeship was the vehicle for transmitting the knowledge required for expert practice in fields from painting and sculpting to medicine and law. It was the natural way to learn. In modern times, apprenticeship has largely been replaced by formal schooling, except in children's learning of language, in some aspects of graduate education, and in on-the-job training. We propose an alternative model of instruction that is accessible within the framework of the typical American classroom. It is a model of instruction that goes back to apprenticeship but incorporates elements of schooling. We call this model "cognitive apprenticeship" (Collins, Brown, and Newman, 1989).

While there are many differences between schooling and apprenticeship methods, we will focus on one. In apprenticeship, learners can see the processes of work: They watch a parent sow, plant, and harvest crops and help as they are able; they assist a tradesman as he crafts a cabinet; they piece together garments under the supervision of a more experienced tailor. Apprenticeship involves learning a physical, tangible activity. But in schooling, the "practice" of problem solving, reading comprehension, and writing is not at all obvious—it is not necessarily observable to the student. In apprenticeship, the processes of the activity are visible. In schooling, the processes of thinking are often invisible to both the students and the teacher. Cognitive apprenticeship is a model of instruction that works to make thinking visible.

In this article, we will present some of the features of traditional apprenticeship and discuss the ways it can be adapted to the teaching and learning of cognitive skills. Then we will present three successful examples—cases in which teachers and researchers have used apprenticeship methods to teach reading, writing, and mathematics.

In the final section, we organize our ideas about the characteristics of successful teaching into a general framework for the design of learning environments, where "environment" includes the content taught, the pedagogical methods employed, the sequencing of learning activities, and the sociology of learning.

TOWARD A SYNTHESIS OF SCHOOLING AND APPRENTICESHIP

Although schools have been relatively successful in organizing and conveying large bodies of conceptual and factual knowledge, standard pedagogical practices render key aspects of expertise invisible to students. Too little attention is paid to the reasoning and strategies that experts employ when they acquire knowledge or put it to work to solve complex or real-life tasks. Where such processes are addressed, the emphasis is on formulaic methods for solving "textbook" problems or on the development of low-level subskills in relative isolation.

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As a result, conceptual and problem-solving knowledge acquired in school remains largely inert for many students. In some cases, knowledge remains bound to surface features of problems as they appear in textbooks and class presentations. For example, Schoenfeld (1985) has found that, in solving mathematics problems, students rely on their knowledge of standard textbook patterns of problem presentation rather than on their knowledge of problem-solving strategies or intrinsic properties of the problems themselves. When they encounter problems that fall outside these patterns, students are often at a loss for what to do. In other cases, students fail to use resources available to them to improve their skills because they lack models of how to tap into those resources. For example, students are unable to make use of potential models of good writing acquired through reading because they have no understanding of how the authors produced such text. Stuck with what Scardamalia and Bereiter (1985) call "knowledge-telling strategies," they are unaware that expert writing involves organizing one's ideas about a topic, elaborating goals to be achieved in the writing, thinking about what the audience is likely to know or believe about the subject, and so on.

To make real differences in students' skill, we need both to understand the nature of expert practice and to devise methods that are appropriate to learning that practice. To do this, we must first recognize that cognitive strategies are central to integrating skills and knowledge in order to accomplish meaningful tasks. They are the organizing principles of expertise, particularly in such domains as reading, writing, and mathematics. Further, because expert practice in these domains rests crucially on the integration of cognitive strategies, we believe that it can best be taught through methods that have traditionally been employed in apprenticeship to transmit complex physical processes and skills.

Traditional Apprenticeship

In traditional apprenticeship, the expert shows the apprentice how to do a task, watches as the apprentice practices portions of the task, and then turns over more and more responsibility until the apprentice is proficient enough to accomplish the task independently. That is the basic notion of apprenticeship: showing the apprentice how to do a task and helping the apprentice to do it. **There are four important aspects of traditional apprenticeship: modeling, scaffolding, fading, and coaching.**

In modeling, the apprentice observes the master demonstrating how to do different parts of the task. The master makes the target processes visible, often by explicitly showing the apprentice what to do. But as Lave and Wenger (in press) point out, in traditional apprenticeship, **much of the learning occurs as apprentices watch others at work.**

Scaffolding is the support the master gives apprentices in carrying out a task. This can range from doing almost the entire task for them to giving occasional hints as to what to do next. **Fading** is the notion of slowly removing the support, giving the apprentice more and more responsibility.

Coaching is the thread running through the entire apprenticeship experience. The master coaches the apprentice through a wide range of activities: choosing tasks, providing hints and scaffolding, evaluating the activities of apprentices and diagnosing the kinds of problems they are having, challenging them and offering encouragement, giving feedback, structuring the ways to do things, working on particular weaknesses. In short, coaching is the process of overseeing the student's learning.

The interplay among observation, scaffolding, and increasingly independent practice aids apprentices both in developing self-monitoring and correction skills and in integrating the skills and conceptual knowledge needed to advance toward expertise. Observation plays a surprisingly key role; Lave (1988) hypothesizes that it aids learners in developing a conceptual model of the target task prior to attempting to execute it. Giving students a conceptual model—a picture of the whole—is an important factor in apprenticeship's success in teaching complex skills without resorting to lengthy practice of isolated subskills, for three related reasons. First, it provides learners with an advanced organizer for their initial attempts to execute a complex skill, thus allowing them to concentrate more of their attention on execution than would otherwise be possible. Second, a conceptual model provides an interpretive structure for making sense of the feedback, hints, and corrections from the master during interactive coaching sessions. Third, it provides an internalized guide for the period when the apprentice is engaged in relatively independent practice.

Another key observation about apprenticeship concerns the social context in which learning takes place. Apprenticeship derives many cognitively important characteristics from being embedded in a subculture in which most, if not all, members are participants in the target skills. As a result, learners have continual access to models of expertise-in-use against which to refine their understanding of complex skills. Moreover, it is not uncommon for apprentices to have access to several masters and thus to a variety of models of expertise. Such richness and variety help them to understand that there may be multiple ways of carrying out a task and to recognize that no one individual embodies all knowledge or expertise. And finally, learners have the opportunity to observe other learners with varying degrees of skill; among other things, this encourages them to view learning as an incrementally staged process, while providing them with concrete benchmarks for their own progress.

From Traditional to Cognitive Apprenticeship

There are three important differences between traditional apprenticeship and the kind of cognitive apprenticeship we propose.

As we said, in traditional apprenticeship, the process of carrying out a task to be learned is usually easily observable. In cognitive apprenticeship, one needs to deliberately bring the thinking to the surface, to make it visible, whether it's in reading, writing, problem solving. The teacher's thinking must be made visible to the students and the student's thinking must be made visible to the teacher. That is the most important difference between traditional apprenticeship and cognitive apprenticeship. Cognitive research, through such methods as protocol analysis, has begun to delineate the cognitive and metacognitive processes that comprise expertise. By bringing these tacit processes into the open, students can observe, enact, and practice them with help from the teacher and from other students.

Second, in traditional apprenticeship, the tasks come up just as they arise in the world: Learning is completely situated in the workplace. When tasks arise in the context of designing and creating tangible products, apprentices naturally understand the reasons for undertaking the process of apprenticeship. They are motivated to work and to learn the subcomponents of the task, because they realize the value of the finished product. They retain what they must do to complete the task, because they have seen the expert's model of the finished product, and so the subcomponents of the task make sense. But in school, teachers are working with a curriculum centered around reading, writing, science, math, history, etc. that is, in large part, divorced from what students and most adults do in their lives. In cognitive apprenticeship, then, the challenge is to situate the abstract tasks of the school curriculum in contexts that make sense to students.

Third, in traditional apprenticeship, the skills to be learned inhere in the task itself: To craft a garment, the apprentice learns some skills unique to tailoring, for example, stitching buttonholes. Cabinetry does not require that the apprentice know anything about buttonholes. In other words, in traditional apprenticeship, it is unlikely that students encounter situations in which the transfer of skills is required. The tasks in schooling, however, demand that students be able to transfer what they learn. In cognitive apprenticeship, the challenge is to present a range of tasks, varying from systematic to diverse, and to encourage students to reflect on and articulate the elements that are common across tasks. As teachers present the targeted skills to students, they can increasingly vary the contexts in which those skills are useful. The goal is to help students generalize the skill, to learn when the skill is or is not applicable, and to transfer the skill independently when faced with novel situations.

In order to translate the model of traditional apprenticeship to cognitive apprenticeship, teachers need to:

- identify the processes of the task and make them visible to students;
- situate abstract tasks in authentic contexts, so that students understand the relevance of the work; and
- vary the diversity of situations and articulate the common aspects so that students can transfer what they learn.

We do not want to argue that cognitive apprenticeship is the only way to learn. Reading a book or listening to a lecture are important ways to learn, particularly in domains where conceptual and factual knowledge are central. Active listeners or readers, who test their understanding and pursue the issues that are raised in their minds, learn things that apprenticeship can never teach. To the degree that readers or listeners are passive, however, they will not learn as much as they would by apprenticeship, because apprenticeship forces them to use their knowledge. Moreover, few people learn to be active readers and listeners on their own, and that is where cognitive apprenticeship is critical—observing the processes by which an expert listener or reader thinks and practicing these skills under the guidance of the expert can teach students to learn on their own more skillfully.

Even in domains that rest on elaborate conceptual and factual underpinnings, students must learn the practice or art of solving problems and carrying out tasks. And to achieve expert practice, some version of apprenticeship remains the method of choice.

COGNITIVE APPRENTICESHIP TEACHING READING WRITING AND MATHEMATICS

In this section, we will briefly describe three success models of teaching in the foundational domains of reading, writing, and mathematics and how these models embody the basic methods of cognitive apprenticeship. These three domains are

foundational not only because they provide the basis for learning and communication in other school subjects but also because they engage cognitive and metacognitive processes that are basic to learning and thinking more generally. Unlike school subjects such as chemistry or history, these domains rest on relatively sparse conceptual and factual underpinnings, turning instead on students' robust and efficient execution of a set of cognitive and metacognitive skills. As such, we believe they are particularly well suited to teaching methods modeled on cognitive apprenticeship.

Reading

Palincsar and Brown's (1984) *reciprocal teaching* of reading exemplifies many of the features of cognitive apprenticeship. It has proved remarkably effective in raising students' scores on reading comprehension tests, especially those of poor readers. The basic method centers on modeling and coaching students in four strategic skills: formulating questions based on the text, summarizing the text, making predictions about what will come next, and clarifying difficulties with the text. Reciprocal teaching was originally designed for middle school students who could decode adequately but had serious comprehension problems; it can be adapted to any age group. The method has been used with groups of two to seven students, as well as individual students. It is called reciprocal teaching because the teacher and students take turns playing the role of teacher.

The procedure is as follows: Both the teacher and students read a paragraph silently. Whoever is playing the role of teacher formulates a question based on the paragraph, constructs a summary, and makes a prediction or clarification, if any come to mind. Initially, the teacher models this process and then turns the role of teacher over to the students. When students first undertake the process, the teacher coaches them extensively on how to construct good questions and summaries, offering prompts and critiquing their efforts. In this way, the teacher provides scaffolding for the students, enabling them to take on whatever portion of the task they are able to. As the students become more proficient, the teacher fades, assuming the role of monitor and providing occasional hints or feedback. The transcript below shows the kind of scaffolding and group interaction that occurs with children during reciprocal teaching.

SAMPLE RECIPROCAL TEACHING DIALOGUE (from Palincsar, 1986)

Text from which students are working:

Crows have another gift. They are great mimics. They can learn to talk and imitate animal sounds. Some have been known to learn 100 words and even whole phrases. They can imitate the squawk of a chicken, the whine of a dog, or the meow of a cat.

Games have a certain fascination to crows. In a game of hide and seek, a crow hides in the hollow of a tree and then sounds a distress caw. The others rush to the spot, look around, then flap away. This may be done over and over, after which the young crow pops out of its hiding place and caws gleefully. Far from being annoyed at this, the flock bursts into loud cawing themselves. They seem to like the trick that has been played on them.

T: Chantel, you're our teacher, right? Why don't you summarize first? Remember, just tell me the most important parts.

S1: Crows have a hundred words they can learn by imitation. They can imitate chickens, the whine of a dog, and cats.

T: Okay. We can shorten that summary a bit.

S2: You could say they can imitate other animals.

T: Oh! Good one! There's a list there, Chantel, did you notice that? It says they can imitate the squawk of a chicken, the whine of a dog or the meow of a cat; and you could call that "animal sounds." Can you ask us a question?

S1: Ain't no questions in here.

S3: The words (sic) that need to be clarified are (sic) "mimics."

S4: That means imitate, right?

T: Right. How did you figure that out, Shirley?

S4: The paragraph.

T: Show us how somebody could figure out what "mimic" means.

S5: They are great mimics. They can learn to talk and imitate animal sounds.

T: Yes, so the next sentence tells you what it means. Very good, anything else needs to be clarified?

All: No.

T: What about that question we need to ask? (pause) What is the second paragraph about, Chantel?

S1: The games they play.

S3: They do things like people do.

S4: What kinds of games do crows play?

S3: Hide and seek. Over and over again.

T: You know what, Larry? That was a real good comparison. One excellent question could be, "How are crows like people?"

S4: They play hide and seek.

T: Good. Any other questions there?

S2: How come the crows don't get annoyed?

S5: Because they like it, they have fun. If I had a crow, I'd tell him he was it and see what he'd do.

T: Let's summarize now and have some predictions.

S1: This was about how they play around in games.

T: Good for you. That's it. Predictions anyone?

S2: Maybe more tricks they play.

S4: Other games.

T: Maybe. So far, they have told us several ways that crows are very smart; they can communicate with one another, they can imitate many sounds, and they play games. Maybe we will read about another way in which they are smart. Who will be the next teacher?

Reciprocal teaching is extremely effective. In a pilot study with individual students who were poor readers, the method raised their reading comprehension test scores from 15 percent to 85 percent accuracy after about twenty training sessions. Six months later the students were still at 60 percent accuracy; recovering to 85 percent only after one session. In a subsequent study with groups of two students, the scores increased from about 30 percent to 80 percent accuracy, with very little change eight weeks later. In classroom studies of groups of four to seven students, test scores increased from about 40 percent to 80 percent correct, again with only a slight decline eight weeks later. These are very dramatic effects for any instructional intervention.

Why is reciprocal teaching so effective? In our analysis, which reflects in part the views of Palincsar and Brown, its effectiveness depends upon the co concurrence of a number of factors.

First, the method engages students in a set of activities that help them form a new conceptual model of the task of reading. In traditional schooling, students learn to identify reading with the subskills of recognizing and pronouncing words and with the activities of scanning text and saying it aloud. Under the new conception, students recognize that reading requires constructive activities, such as formulating questions and making summaries and predictions, as well as evaluative ones, such

as analyzing and clarifying the pints of difficulty. As Palincsar points out (1987), working with a text in a discussion format is not the same as teaching isolated comprehension skills – like how to identify the main idea. With reciprocal teaching, the strategies students learn are in the service of a larger purpose: to understand what they are and to develop the critical ability to *read to learn*.

The second factor that we think is critical for the success of reciprocal teaching is that the teacher models expert strategies in a shared problem context of knowing that they will soon undertake the same task. After they have tried to do it themselves, and perhaps had difficulties, they listen with new knowledge about the task. That is, they can compare their own questions or summaries generated by the group. They can reflect on any differences, trying to understand what led to those differences. We have argued elsewhere that this kind of reflection is critical to learning (Collins and Brown, 1988).

Third, the technique pf providing scaffolding is crucial in the success of reciprocal teaching for several reasons. Most importantly, it decomposes the task as necessary for the students to carry it out, thereby helping them to see how, in detail, to go about it. For example, in formulating questions, the teacher might want to see if the student can generate a question on his or her own; if not, she might suggest starting with a "Why" question about the agent in the story. If that fails, she might generate one herself and ask the student to reformulate it in his or her own words. In this way, it gets students started in the new skills, giving them a "feel" for the skills and helping them develop confidence that they can do them. With successful scaffolding techniques, students get as much support as they need to carry out the task, but no more. Hints and modeling are then gradually faded out, with students taking on more and more of the task as they become more skillful. These techniques of scaffolding and fading slowly build students' confidence that they can master the skills required.

The final aspect of reciprocal teaching that we think is critical is having students assume the dual roles of producer and critic. They not only must produce good questions and summaries, but they also learn to evaluate the summaries or questions of others. By becoming critics as well as producers, students are forced to articulate their knowledge about what makes a good question, prediction, or summary. This knowledge then becomes more readily available for application to their own summaries and questions, thus improving a crucial aspect of their metacognitive skills. Moreover, once articulated, this knowledge can no longer simply reside in tacit form. It becomes more available for performing a variety of tasks; that is, it is freed from its contextual binding and can be used in many different contexts.

Writing

Scardamalia and Bereiter (1985; Scardamalia, Bereiter, and Steinbach, 1984) have developed an approach to the teaching of writing that relies on elements of cognitive apprenticeship. Based on contrasting models of novice and expert writing strategies, the approach provides explicit procedural supports, in the form of prompts, that are aimed at helping students adopt more sophisticated writing strategies. Like other exemplars of cognitive apprenticeship, their approach is designed to give students a grasp of the complex activities involved in expertise by explicit modeling of expert processes, gradually reduced support or scaffolding for students attempting to engage in the processes, and opportunities for reflection on their own and others' efforts.

According to Bereiter and Scardamalia (1987), children who are novices in writing use a "knowledge telling" strategy. When given a topic to write on, they immediately produce text by writing their first idea, then their next idea, and so on, until they run out of ideas, at which point they stop. This very simple control strategy fineses most of the difficulties in composing. In contrast, experts spend time not only writing but also planning what they are going to write and revising what they have written (Hayes and Flower, 1980). As a result, they engage in a process that Scardamalia and Bereiter call "knowledge transforming," which incorporates the linear generation of text but is organized around a more complex structure of goal setting and problem solving.

To encourage students to adopt a more sophisticated writing strategy, Scardamalia and Bereiter have developed a detailed cognitive analysis of the activities of expert writers. This analysis provides the basis for a set of prompts, *procedural facilitations* that are designed to reduce students' information-processing burden by allowing them to select from a limited number of diagnostic statements. For example, planning is broken down into five general processes or goals: (a) generating a new idea, (b) improving an idea, (c) elaborating on an idea, (d) identifying goals, and (e) putting ideas into a cohesive whole. For each process, they have developed a number of specific prompts, designed to aid students in their planning, as shown below. These prompts, which are akin to the suggestions made by the teacher in reciprocal teaching, serve to simplify the complex process of elaborating on one's plans by suggesting specific lines of thinking for students to follow. A set of prompts has been developed for the revision process as well (Scardamalia and Bereiter, 1983, 1985).

PLANNING CUES FOR OPINION ESSAYS

(From Scardamalia et al., 1984)

NEW IDEA

An even better idea is ...
An important point I haven't considered yet is ...
A better argument would be ...
A different aspect would be ...
A whole new way to think of this topic is ...
No one will have thought of ...

IMPROVE

I'm not being very clear about what I just said so ...
I could make my main point clearer ...
A criticism I should deal with in my paper is ...
I really think this isn't necessary because ...
I'm getting off the topic so ...
This isn't very convincing because ...
But many readers won't agree that ...
To liven this up I'll ...

ELABORATE

An example of this ...
This is true, but it's not sufficient so ...
My own feelings about this are ...
I'll change this a little by ...
The reason I think so ...
Another reason that's good ...
I could develop this idea by adding ...
Another way to put it would be ...
A good point on the other side of the argument is ...

GOALS

A goal I think I could write to ...
My purpose ...

PUTTING IT TOGETHER

If I want to start off with my strongest idea, I'll ...
I can tie this together by ...
My main point is ...

Scardamalia and Bereiter's teaching method, like reciprocal teaching, proceeds through a combination of modeling, coaching, scaffolding, and fading. First, the teacher models how to use the prompts, which are written on cue cards, in generating ideas about a topic she is going to write on. The example below illustrates the kind of modeling done by a teacher during an early phase of instruction. Then the students each try to plan an essay on a new topic using the cue cards, a process the students call "soloing." While each student practices soloing, the teacher as well as other students evaluate the soloist's performance, by, for example, noticing discrepancies between the soloist's stated goals (e.g., to get readers to appreciate the difficulties of modern dance) and their proposed plans (to describe different kinds of dance). Students also become involved in discussing how to resolve problems that the soloist could not solve. As in the reciprocal teaching method, assumption of the role either of critic or producer is incremental, with students taking over more and more of the monitoring and

problem-solving process from the teacher as their skills improve. Moreover, as the students internalize the processes invoked by the prompts, the cue cards are gradually faded out as well.

A TEACHER MODELS GETTING STARTED

ASSIGNMENT

(Suggested by students)

Write an essay on the topic "Today's Rock Stars Are More Talented than Musicians of Long Ago."

THINKING-ALOUD EXCERPT

I don't know a thing about modern rock stars. I can't think of the name of even one rock star. How about, David Bowie or Mick Jagger ... But many readers won't agree that they are modern rock stars. I think they're both as old as I am. Let's see, my own feelings about this are ... that I doubt if today's rock stars are more talented than ever. Anyhow, how would I know? I can't argue this ... I need a new idea ... An important point I haven't considered yet is ... ah ... well ... what do we mean by talent? Am I talking about musical talent or ability to entertain-to do acrobatics? Hey, I may have a way into this topic. I could develop this idea by ...

Note: Underlined phrases represent selection from planning cues similar to those shown in the outline for opinion essays.

Scardamalia and Bereiter have tested the effects of their approach on both the initial planning and the revision of student compositions. In a series of studies (Bereiter and Scardamalia, 1987), procedural facilitations were developed to help elementary school students evaluate, diagnose, and decide on revisions for their compositions. Results showed that each type of support was effective, independent of the other supports. And when all the facilitations were combined, they resulted in superior revisions for nearly every student and a tenfold increase in the frequency of idea-level revisions, without any decrease in stylistic revisions. Another study (Scardamalia, et al., 1984) investigated the use of procedural cues to facilitate planning. Students gave the teacher assignments, often ones thought to be difficult for her. She used cues like those shown above to facilitate planning, modeling the process of using the cues to stimulate her thinking about the assignment. Pre- and post-comparisons of think-aloud protocols showed significantly more reflective activity on the part of experimental-group students, even when prompts were no longer available to them. Time spent in planning increased tenfold. And when students were given unrestricted time to plan, the texts of experimental-group students were judged significantly superior in thought content.

Clearly, Scardamalia and Bereiter's methods bring about significant changes in the nature and quality of student writing. In addition to the methods already discussed, we believe that there are two key reasons for their success. First, as in the reciprocal teaching approach to reading, their methods help students build a new conception of the writing process. Students initially consider writing to be a linear process of knowledge telling. By explicitly modeling and scaffolding expert processes, they are providing students with a new model of writing that involves planning and revising. Most students found this view of writing entirely new and showed it in their comments ("I don't usually ask myself those questions," "I never thought closely about what I wrote," and "They helped me look over the sentence, which I don't usually do."). Moreover, because students rarely, if ever, see writers at work, they tend to hold naive beliefs about the nature of expert writing, thinking that writing is a smooth and easy process for "good" writers. Live modeling helps to convey that this is not the case. The model demonstrates struggles, false starts, discouragement, and the like.

Second, because writing is a complex task, a key component of expertise are the control strategies by which the writer organizes the numerous lines of thinking involved in producing high-quality text. A clear need of student writers, therefore, is to develop more useful control strategies than evidenced in "knowledge telling." Scardamalia and Bereiter's methods encourage this development in an interesting way: The cue cards act to externalize not only the basic processes involved in planning but also to help students to keep track of the higher order intentions (such as generating an idea, elaborating or improving on an idea, and so on) that organize these basic processes.

Mathematical Problem Solving*

Our third example is Schoenfeld's (1983, 1985) method for teaching mathematical problem solving to college students. Like the other two, this method is based on a new analysis of the knowledge and processes required for expertise, where

expertise is understood as the ability to carry out complex problem-solving tasks. And like the other two, this method incorporates the basic elements of a cognitive apprenticeship, using the methods of modeling, coaching, and fading and of encouraging student reflection on their own problem-solving processes. In addition, Schoenfeld's work introduces some new concerns, leading the way toward articulation of a more general framework for the development and evaluation of ideal learning environments.

One distinction between novices and experts in mathematics is that experts employ heuristic methods, usually acquired tacitly through long experience, to facilitate their problem solving. To teach these methods directly, Schoenfeld formulated a set of heuristic strategies, derived from the problem-solving heuristics of Polya (1945). These *heuristic strategies* consist of rules of thumb for how to approach a given problem. One such heuristic specifies how to distinguish special cases in solving math problems: for example, for series problems in which there is an integer parameter in the problem statement, one should try the cases $n = 1, 2, 3, 4$, and try to make an induction on those cases; for geometry problems, one should first examine cases with minimal complexity, such as regular polygons and right triangles. Schoenfeld taught a number of these heuristics and how to apply them in different kinds of math problems. In his experiments, Schoenfeld found that learning these strategies significantly increased students' problem-solving abilities.

But as he studied students' problem solving further, he became aware of other critical factors affecting their skill, in particular what he calls *control strategies*. In Schoenfeld's analysis, control strategies are concerned with executive decisions, such as generating alternative courses of action, evaluating which will get you closer to a solution, evaluating which you are most likely to be able to carry out, considering what heuristics might apply, evaluating whether you are making progress toward a solution, and so on. Schoenfeld found that it was critical to teach control strategies, as well as heuristics.

As with the reading and writing examples, explicit teaching of these elements of expert practice yields a fundamentally new understanding of the domain for students. To students, learning mathematics had meant learning a set of mathematical operations and methods. Schoenfeld's method is teaching students that doing mathematics consists not only in applying problem-solving procedures but in reasoning about and managing problems using heuristics and control strategies.

Schoenfeld's teaching employs the elements of modeling, coaching, scaffolding, and fading in a variety of activities designed to highlight different aspects of the cognitive processes and knowledge structures required for expertise. For example, as a way of introducing new heuristics, he models their selection and use in solving problems for which they are particularly relevant. In this way, he exhibits the thinking processes (heuristics and control strategies) that go on in expert problem solving but focuses student observation on the use and management of specific heuristics. The example in the sidebar provides a protocol from one such modeling.

A MATHEMATICIAN THINKS OUT LOUD

(from Schoenfeld, 1983)

Problem

Let $P(x)$ and $Q(x)$ be two polynomials with "reversed" coefficients:

$$\begin{aligned} P(x) &= a_n x^n + a_{n-1} x^{n-1} + \\ &\dots + a_2 x^2 a_1 x + a_0 \\ Q(x) &= a_0 x^n + a_1 x^{n-1} + \\ &\dots + a_{n-2} x^2 a_{n-1} x + a_n, \end{aligned}$$

where $a_n \neq 0 \neq a_0$. What is the relationship between the roots of $P(x)$ and those of $Q(x)$? Prove your answer.

Expert Model

What do you do when you face a problem like this? I have no general procedure for finding the roots of a polynomial, much less for comparing the roots of two of them. Probably the best thing to do for the time being is to look at some simple examples and hope I can develop some intuition from them. Instead of looking at a pair of arbitrary polynomials, maybe I should look at a pair of quadratics: at least I can solve those. So, what happens if

$$P(x) = ax^2 + bx + c$$

and

$$Q(x) = cx^2 + bx + a?$$

* For those of you for whom it has been a while since you grappled with college math, let us assure you that you need not follow the substance of the math in this example in order to understand and appreciate what Schoenfeld is doing pedagogically when he brings to the surface reasoning processes that are normally covert.

The roots are

$$\frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$\frac{-b \pm \sqrt{b^2 - 4ac}}{2c}$$

respectively.

That's certainly suggestive, because they have the same numerator, but I don't really see anything that I can push or that'll generalize. I'll give this a minute or two, but I may have to try something else....

Well, just for the record, let me look at the linear case. If $P(x) = ax + b$ and $Q(x) = bx + a$, the roots are $-b/a$ and $-a/b$ respectively.

They're reciprocals, but that's not too interesting in itself. Let me go back to quadratics. I still don't have much of a feel for what's going on. I'll do a couple of easy examples, and look for some sort of a pattern. The clever thing to do may be to pick polynomials I can factor; that way it'll be easy to keep track of the roots. All right, how about something easy like $(x + 2)(x + 3)$?

Then $P(x) = x^2 + 5x + 6$, with roots -2 and -3. So,
 $Q(x) = 6x^2 + 5x + 1 = (2x + 1)(3x + 1)$, with roots $-1/2$ and $-1/3$.

Those are reciprocals too. Now that's interesting.

How about $P(x) = (3x + 5)(2x - 7) = 6x^2 - 11x - 35$? Its roots are $-5/3$ and $7/2$;

$$Q(x) = -35x^2 - 11x + 6 = -(35x^2 + 11x - 6) = -(7x - 2)(5x + 3).$$

All right, the roots are $2/7$ and $-3/5$. They're reciprocals again, and this time it can't be an accident. Better yet, took at the factors: they're reversed! What about

$$P(x) (ax + b)(cx + d) = acx^2 + (bc + ad)x + bd ? \text{ Then}$$

$$Q(x) bdx^2 + (ad + bc)x + ac = (bx + a)(dx + c).$$

Aha! It works again, and I think this will generalize....

At this point there are two ways to go. I hypothesize that the roots of $P(x)$ are the reciprocals of the roots of $Q(x)$, in general. (If I'm not yet sure, I should try a factorable cubic or two.) Now, I can try to generalize the argument above, but it's not all that straightforward; not every polynomial can be factored, and keeping track of the coefficients may not be that easy. It may be worth stopping, re-phrasing my conjecture, and trying it from scratch:

Let $P(x)$ and $Q(x)$ be two polynomials with "reversed" coefficients. Prove that the roots of $P(x)$ and $Q(x)$ are reciprocals.

All right, let's take a look at what the problem asks for. What does it mean for some number, say r , to be a root of $P(x)$? It means that $P(r) = 0$. Now the conjecture says that the reciprocal of r is supposed to be a root to $Q(x)$. That says that $Q(1/r) = 0$. Strange. Let me go back to the quadratic case, and see what happens.

Let $P(x) = ax^2 + bx + c$, and $Q(x) = cx^2 + bx + a$. If r is a root of $P(x)$, then $P(r) = ar^2 + br + c = 0$. Now what does $Q(1/r)$ look like?

$$Q(1/r) = c(1/r)^2 + b(1/r) + a = \frac{c + br + ar^2}{r^2} = \frac{P(r)}{r^2} = \frac{0}{r^2} = 0$$

So it works, and this argument will generalize. Now I can write up a proof

Proof...

Let r be a root of $P(x)$, so that $P(r) = 0$. Observe that $r \neq 0$,

since $a_0 \neq 0$. Further,

$Q(1/r) = a_0(1/r)^n + a_1(1/r)^{n-1} + \dots + a_{n-2}(1/r) + a_n = (1/r^n)(a_0 + a_1r + a_2r^2 + \dots + a_{n-2}r^{n-2} + a_{n-1}r^{n-1} + a_n r^n) = (1/r^n)P(r) = 0$, so that $(1/r)$ is a root of $Q(x)$.

Conversely, if S is a root of $Q(x)$, we see that $P(1/S) = 0$. Q.E.D.

All right, now it's time for a postmortem. Observe that the proof, like a classical mathematical argument, is quite terse and presents the results of a thought process. But where did the inspiration for the proof come from? If you go back over the way that the argument evolved, you'll see there were two major breakthroughs.

The first had to do with understanding the problem, with getting a feel for it. The problem statement, in its full generality, offered little in the way of assistance. What we did was to *examine special cases* in order to look for a pattern. More specifically, our first attempt at special cases-looking at the quadratic formula didn't provide much insight. We had to get even more specific, as follows: *Look at a series of straightforward examples that are easy to calculate, in order to see if some sort of pattern emerges. With luck, you might be able to generalize the pattern.* In this case, we were looking for roots of polynomials, so we chose easily factorable ones. Obviously, different circumstances will lead to different choices. But that strategy allowed us to make a conjecture.

The second breakthrough came after we made the conjecture. Although we had some idea of why it ought to be true, the argument looked messy, and we stopped to reconsider for a while. What we did at that point was important, and is often overlooked: *We went back to the conditions of the problem, explored them, and looked for tangible connections between them and the results we wanted.* Questions like "what does it mean for r to be a root of $P(x)$?", "what does the reciprocal of r look like?" and "what does it mean for $(1/r)$ to be a root of $Q(x)$?" may seem almost trivial in isolation, but they focused our attention on the very things that gave us a solution.

Next, he gives the class problems to solve that lend themselves to the use of the heuristics he has introduced. During this collective problem solving, he acts as a moderator, soliciting heuristics and solution techniques from the students while modeling the various control strategies for making judgments about how best to proceed. This division of labor has several effects. First, he turns over some of the problem-solving process to students by having them generate alternative courses of action but provides major support or scaffolding by managing the decisions about which course to pursue, when to change course, etc. Second, significantly, he no longer models the entire expert problem-solving process but a portion of it. In this way, he shifts the focus from the application or use of specific heuristics to the application or use of control strategies in managing those heuristics.

Like Scardamalia and Bereiter, Schoenfeld employs a third kind of modeling that is designed to change students' assumptions about the nature of expert problem solving. He challenges students to find difficult problems and at the beginning of each class offers to try to solve one of their problems. Occasionally, the problems are hard enough that the students see him flounder in the face of real difficulties. During these sessions, he models for students not only the use of heuristics and control strategies but the fact that one's strategies sometimes fail. In contrast, textbook solutions and classroom demonstrations generally illustrate only the successful solution path, not the search space that contains all of the deadend attempts. Such solutions reveal neither the exploration in searching for a good method nor the necessary evaluation of the exploration. Seeing how experts deal with problems that are difficult for them is critical to students' developing a belief in their own capabilities. Even experts stumble, flounder, and abandon their search for a solution until another time. Witnessing these struggles helps students realize that thrashing is neither unique to them nor a sign of incompetence.

In addition to class demonstrations and collective problem solving, Schoenfeld has students participate in small-group problem-solving sessions. During these sessions, Schoenfeld acts as a "consultant" to make sure that the groups are

proceeding in a reasonable fashion. Typically he asks three questions: What are they doing, why are they doing it, and how will success in what they are doing help them find a solution to the problem? Asking these questions serves two purposes: First, it encourages the students to reflect on their activities, thus promoting the development of general self-monitoring and

diagnostic skills; second, it encourages them to articulate the reasoning behind their choices as they exercise control strategies. Gradually, the students, in anticipating his questioning, come to ask the questions of themselves, thus gaining control over reflective and metacognitive processes in their problem solving. In these sessions, then, he is fading relative to both helping students generate heuristics and, ultimately, to exercising control over the process. In this way, they gradually gain control over the entire problem-solving process.

Schoenfeld (1983) advocates small-group problem solving for several reasons. First, it gives the teacher a chance to coach students while they are engaged in semi-independent problem solving; he cannot really coach them effectively on homework problems or class problems. Second, the necessity for group decision making in choosing among alternative solution methods provokes articulation, through discussion and argumentation, of the issues involved in exercising control processes. Such discussion encourages the development of the metacognitive skills involved, for example, monitoring and evaluating one's progress. Third, students get little opportunity in school to engage in collaborative efforts; group problem solving gives them practice in the kind of collaboration prevalent in real-world problem solving. Fourth, students are often insecure about their abilities, especially if they have difficulties with the problems. Seeing other students struggle alleviates some of this insecurity as students realize that difficulties in understanding are not unique to them, thus contributing to an enhancement of their beliefs about self, relative to others.

We believe that there is another important reason that small-group problem solving is useful for learning: the differentiation and externalization of the roles and activities involved in solving complex problems. Successful problem solving requires that one assume at least three different, though interrelated, roles at different points in the problem-solving process: that of moderator or executive, that of generator of alternative paths, and that of critic of alternatives. Small-group problem solving differentiates and externalizes these roles: different people naturally take on different roles, and problem solving proceeds along these lines. And here, as in reciprocal teaching, students may play different roles, so that they gain practice in all the activities they need to internalize.

There is one final aspect of Schoenfeld's method that we think is critical and that is different from the other methods we have discussed: What he calls postmortem analysis. As with other aspects of Schoenfeld's method, students alternate with the teacher in producing postmortem analyses. First, after modeling the problem-solving process for a given problem, Schoenfeld recounts the solution method, highlighting those features of the process that can be generalized (see math sidebar). For example, he might note the heuristics that were employed, the points in the solution process where he or the class engaged in generating alternatives, the reasons for the decision to pursue one alternative before another, and so on. In short, he provides what Collins and Brown (1988) have labeled an abstracted replay, that is, a recapitulation of some process designed to focus students' attention on the critical decisions or actions. Postmortem analysis also occurs when individual students explain the process by which they solved their homework problems. Here students are required to generate an abstracted replay of their own problem-solving process, as the basis for a class critique of their methods. The alternation between expert and student postmortem analyses enables the class to compare student problem-solving processes and strategies with those of the expert; such comparisons provide the basis for diagnosing student difficulties and for making incremental adjustments in student performance.

A FRAMEWORK FOR DESIGNING LEARNING ENVIRONMENTS

Our discussion of cognitive apprenticeship raises numerous pedagogical and theoretical issues that we believe are important to the design of learning environments generally. To facilitate consideration of these issues, we have developed a framework consisting of four dimensions that constitute any learning environment: content, method, sequence, and sociology. Relevant to each of these dimensions is a set of characteristics that we believe should be considered in constructing or evaluating learning environments. These characteristics are summarized in the adjacent sidebar and described in detail below, with examples from reading, writing, and mathematics.

Content

Recent cognitive research has begun to differentiate the types of knowledge required for expertise. In particular, researchers have begun to distinguish among the concepts, facts, and procedures associated with expertise and various types of strategic knowledge. We use the term strategic knowledge to refer to the usually tacit knowledge that underlies an expert's ability to make use of concepts, facts, and procedures as necessary to solve problems and accomplish tasks. This sort of expert problem-solving knowledge involves problem-solving heuristics (or "rules of thumb") and the strategies that control the problem-solving process. Another type of strategic knowledge, often overlooked, includes the learning strategies that experts use to acquire new concepts, facts, and procedures in their own or another field.

We should emphasize that much of experts' strategic knowledge depends on their knowledge of facts, concepts, and procedures. For instance, in the math example discussed earlier, Schoenfeld's students could not begin to apply the strategies he is teaching if they did not have a solid grounding in mathematical knowledge.

1. *Domain knowledge* includes the concepts, facts, and procedures explicitly identified with a particular subject matter; these are generally explicated in school textbooks, class lectures, and demonstrations. This kind of knowledge, although certainly important, provides insufficient clues for many students about how to solve problems and accomplish tasks in a domain. Moreover, when it is learned in isolation from realistic problem contexts and expert problem-solving practices, domain knowledge tends to remain inert in situations for which it is appropriate, even for successful students. And finally, although at least some concepts can be formally described, many of the crucial subtleties of their meaning are best acquired through applying them in a variety of problem situations. Indeed, it is only through encountering them in real problem solving that most students will learn the boundary conditions and entailments of much of their domain knowledge. Examples of domain knowledge in reading are vocabulary, syntax, and phonics rules.

2. *Heuristic strategies* are generally effective techniques and approaches for accomplishing tasks that might be regarded as "tricks of the trade"; they don't always work, but when they do, they are quite helpful. Most heuristics are tacitly acquired by experts through the practice of solving problems; however, there have been noteworthy attempts to address heuristic learning explicitly (Schoenfeld, 1985). For example, a standard heuristic for writing is to plan to rewrite the introduction and, therefore, to spend relatively little time crafting it in the first draft. In mathematics, a heuristic for solving problems is to try to find a solution for simple cases and see if the solution generalizes.

3. Control strategies, as the name suggests, control the process of carrying out a task. These are sometimes referred to as "metacognitive" strategies (Palinscar and Brown, 1984; Schoenfeld, 1985). As students acquire more and more heuristics for solving problems, they encounter a new management or control problem: how to select among the possible problem-solving strategies, how to decide when to change strategies, and so on. Control strategies have monitoring, diagnostic, and remedial components; decisions about how to proceed in a task generally depend on an assessment of one's current state relative to one's goals, on an analysis of current difficulties, and on the strategies available for dealing with difficulties. For example, a comprehension-monitoring strategy might be to try to state the main point of a section one has just read; if one cannot do so, then one has not understood the text, and it might be best to reread parts of the text. In mathematics, a simple control strategy for solving a complex problem might be to switch to a new part of a problem if one is stuck.

4. *Learning strategies* are strategies for learning any of the other kinds of content described above. Knowledge about how to learn ranges from general strategies for exploring a new domain to more specific strategies for extending or reconfiguring knowledge in solving problems or carrying out complex tasks. For example, if students want to learn to solve problems better, they need to learn how to relate each step in the example problems worked in textbooks to the principles discussed in the text (Chi, et al., 1989). If students want to write better, they need to find people to read their writing who can give helpful critiques and explain the reasoning underlying the critiques (most people cannot). They also need to learn to analyze other's texts for strengths and weaknesses.

Method

Teaching methods should be designed to give students the opportunity to observe, engage in, and invent or discover expert strategies in context. Such an approach will enable students to see how these strategies combine with their factual and conceptual knowledge and how they use a variety of resources in the social and physical environment. The six teaching methods advocated here fall roughly into three groups: the first three (modeling, coaching, and scaffolding) are the core of cognitive apprenticeship, designed to help students acquire an integrated set of skills through processes of observation and guided practice. The next two (articulation and reflection) are methods designed to help students both to focus their observations of expert problem solving and to gain conscious access to (and control of) their own problem-solving strategies. The final method (exploration) is aimed at encouraging learner autonomy, not only in carrying out expert problem-solving processes but also in defining or formulating the problems to be solved.

1. *Modeling* involves an expert's performing a task so that the students can observe and build a conceptual model of the processes that are required to accomplish it. In cognitive domains, this requires the externalization of usually internal processes and activities—specifically, the heuristics and control processes by which experts apply their basic conceptual and procedural knowledge. For example, a teacher might model the reading process by reading aloud in one voice, while verbalizing her thought processes in another voice (Collins and Smith, 1982). In mathematics, as described above, Schoenfeld models the process of solving problems by having students bring difficult new problems for him to solve in class.

2. *Coaching* consists of observing students while they carry out a task and offering hints, scaffolding, feedback, modeling, reminders, and new tasks aimed at bringing their performance closer to expert performance. Coaching may serve to direct students' attention to a previously unnoticed aspect of the task or simply to remind the student of some aspect of the task that is known but has been temporarily overlooked. The content of the coaching interaction is immediately related to specific events or problems that arise as the student attempts to accomplish the target task. In Palincsar and Brown's reciprocal teaching of reading, the teacher coaches students while they ask questions, clarify their difficulties, generate summaries, and make predictions.

3. *Scaffolding* refers to the supports the teacher provides to help the student carry out the task. These supports can take either the forms of suggestions or help, as in reciprocal teaching, or they can take the form of physical supports, as with the cue cards used by Scardamalia, Bereiter, and Steinbach to facilitate writing, or the short skis used to teach downhill skiing (Burton, Brown, and Fisher, 1984). When scaffolding is provided by a teacher, it involves the teacher in executing parts of the task that the student cannot yet manage. A requisite to such scaffolding is accurate diagnosis of the student's current skill level or difficulty and the availability of an intermediate step at the appropriate level of difficulty in carrying out the target activity. Fading involves the gradual removal of supports until students are on their own.

4. *Articulation* involves any method of getting students to articulate their knowledge, reasoning, or problem-solving processes. We have identified several different methods of articulation. First, inquiry teaching (Collins and Stevens, 1982, 1983) is a strategy of questioning students to lead them to articulate and refine their understanding of concepts and procedures in different domains. For example, an inquiry teacher in reading might systematically question students about why one summary of the text is good but another is poor, to get the students to formulate an explicit model of a good summary. Second, teachers might encourage students to articulate their thoughts as they carry out their problem solving, as do Scardamalia, et al. Third, they might have students assume the critic or monitor role in cooperative activities, as do all three models we discussed, and thereby lead students to formulate and articulate their ideas to other students.

5. *Reflection* involves enabling students to compare their own problem-solving processes with those of an expert, another student, and ultimately, an internal cognitive model of expertise. Reflection is enhanced by the use of various techniques for reproducing or "replaying" the performances of both expert and novice for comparison. The level of detail for a replay may vary depending on the student's stage of learning, but usually some form of "abstracted replay," in which the critical features of expert and student performance are highlighted, is desirable (Collins and Brown, 1988). For reading or writing, methods to encourage reflection might consist of recording students as they think out loud and then replaying the tape for comparison with the thinking of experts and other students.

6. *Exploration* involves pushing students into a mode of problem solving on their own. Forcing them to do exploration is critical, if they are to learn how to frame questions or problems that are interesting and that they can solve. Exploration is the natural culmination of the fading of supports. It involves not only fading in problem solving but fading in problem setting as well. But students do not know *a priori* how to explore a domain productively. So exploration strategies need to be taught as part of learning strategies more generally. Exploration as a method of teaching involves setting general goals for students and then encouraging them to focus on particular subgoals of interest to them, or even to revise the general goals as they come upon something more interesting to pursue. For example, in reading, the teacher might send the students to the library to investigate theories about why the stock market crashed in 1929. In writing, students might be encouraged to write an essay defending the most outrageous thesis they can devise. In mathematics, students might be asked to generate and test hypotheses about teenage behavior given a database on teenagers detailing their backgrounds and how they spend their time and money.

PRINCIPLES FOR DESIGNING COGNITIVE APPRENTICESHIP ENVIRONMENTS

CONTENT types of knowledge required for expertise

Domain knowledge subject matter specific concepts, facts, and procedures

Heuristic strategies generally applicable techniques for accomplishing tasks

Control strategies general approaches for directing one's solution process

Learning strategies knowledge about how to learn new concepts, facts, and procedures

METHOD ways to promote the development of expertise

Modeling teacher performs a task so students can observe

Coaching teacher observes and facilitates while students perform a task

Scaffolding teacher provides supports to help the student perform a task

Articulation teacher encourages students to verbalize their knowledge and thinking

Reflection teacher enables students to compare their performance with others

Exploration teacher invites students to pose and solve their own problems

SEQUENCING keys to ordering learning activities

Global before local skills focus on conceptualizing the whole task before executing the parts

Increasing complexity meaningful tasks gradually increasing in difficulty

Increasing diversity practice in a variety of situations to emphasize broad application

SOCIOLOGY social characteristics of learning environments

Situated learning students learn in the context of working on realistic tasks

Community of practice communication about different ways to accomplish meaningful tasks

Intrinsic motivation students set personal goals to seek skills and solutions

Cooperation students work together to accomplish their goals

Sequencing

In sequencing activities for students, it is important to give students tasks that structure their learning but that preserve the meaningfulness of what they are doing. This leads us to three principles that must be balanced in sequencing activities for students.

1. *Global before local skills*. In tailoring (Lave, 1988), apprentices learn to put together a garment from precut pieces before learning to cut out the pieces themselves. The chief effect of this sequencing principle is to allow students to build a conceptual map, so to speak, before attending to the details of the terrain (Norman, 1973). In general, having students build a conceptual model of the target skill or process (which is also encouraged by expert modeling) accomplishes two things: First, even when the learner is able to accomplish only a portion of a task, having a clear conceptual model of the overall activity helps him make sense of the portion that he is carrying out. Second, the presence of a clear conceptual model of the target task acts as a guide for the learner's performance, thus improving his ability to monitor his own progress and to develop attendant self-correction skills. This principle requires some form of scaffolding. In algebra, for example, students may be relieved of having to carry out low-level computations in which they lack skill in order to concentrate on the higher-order reasoning and strategies required to solve an interesting problem (Brown, 1985).

2. *Increasing complexity* refers to the construction of a sequence of tasks such that more and more of the skills and concepts necessary for expert performance are required (VanLehn and Brown, 1980; Burton, Brown, and Fisher, 1984; White, 1984). For example, in the tailoring apprenticeship described by Lave, apprentices first learn to construct drawers, which have straight lines, few pieces, and no special features, such as waistbands or pockets. They then learn to construct blouses, which require curved lines, patch pockets, and the integration of a complex subpiece, the collar. There are two mechanisms for helping students manage increasing complexity. The first mechanism is to sequence tasks in order to control task complexity. The second key mechanism is the use of scaffolding, which enables students to handle at the outset, with the support of the teacher or other helper, the complex set of activities needed to accomplish any interesting task. For example, in reading, increasing task complexity might consist of progressing from relatively short texts, employing straightforward syntax and concrete description, to texts in which complex interrelated ideas and the use of abstractions make interpretation difficult.

3. *Increasing diversity* refers to the construction of a sequence of tasks in which a wider and wider variety of strategies or skills are required. Although it is important to practice a new strategy or skill repeatedly in a sequence of (increasingly

complex) tasks, as a skill becomes well learned, it becomes increasingly important that tasks requiring a diversity of skills and strategies be introduced so that the student learns to distinguish the conditions under which they do (and do not) apply. Moreover, as students learn to apply skills to more diverse problems, their strategies acquire a richer net of contextual associations and thus are more readily available for use with unfamiliar or novel problems. For reading, task diversity might be attained by mixing reading for pleasure, reading for memory (studying), and reading to find out some particular information in the context of some other task.

Sociology

The final dimension in our framework concerns the sociology of the learning environment. For example, tailoring apprentices learn their craft not in a special, segregated learning environment but in a busy tailoring shop. They are surrounded both by masters and other apprentices, all engaged in the target skills at varying levels of expertise. And they are expected, from the beginning, to engage in activities that contribute directly to the production of actual garments, advancing quickly toward independent, skilled production. As a result, apprentices learn skills in the context of their application to realistic problems, within a culture focused on and defined by expert practice. Furthermore, certain aspects of the social organization of apprenticeship encourage productive beliefs about the nature of learning and of expertise that are significant to learners' motivation, confidence, and most importantly, their orientation toward problems that they encounter as they learn. From our consideration of these general issues, we have abstracted critical characteristics affecting the sociology of learning.

1. *Situated learning*. A critical element of fostering learning is to have students carry out tasks and solve problems in an environment that reflects the multiple uses to which their knowledge will be put in the future. Situated learning serves several different purposes. First, students come to understand the purposes or uses of the knowledge they are learning. Second, they learn by actively using knowledge rather than passively receiving it. Third, they learn the different conditions under which their knowledge can be applied. As we pointed out in the discussion of Schoenfeld's work, students have to learn when to use a particular strategy and when not to use it (i.e., the application conditions of their knowledge). Fourth, learning in multiple contexts induces the abstraction of knowledge, so that students acquire knowledge in a dual form, both tied to the contexts of its uses and independent of any particular context. This unbinding of knowledge from a specific context fosters its transfer to new problems and new domains. For example, reading and writing instruction might be situated in the context of students putting together a book on what they learn about science. Dewey created a situated learning environment in his experimental school by having the students design and build a clubhouse (Cuban, 1984), a task that emphasizes arithmetic and planning skills.

2. *Community of practice* refers to the creation of a learning environment in which the participants actively communicate about and engage in the skills involved in expertise, where expertise is understood as the practice of solving problems and carrying out tasks in a domain. Such a community leads to a sense of ownership, characterized by personal investment and mutual dependency. It can't be forced, but it can be fostered by common projects and shared experiences. Activities designed to engender a community of practice for reading might engage students and teacher in discussing how they interpret what they read and use those interpretations for a wide variety of purposes, including those that arise in other classes or domains.

3. *Intrinsic motivation*. Related to the issue of situated learning and the creation of a community of practice is the need to promote intrinsic motivation for learning. Lepper and Greene (1979) and Malone (1981) discuss the importance of creating learning environments in which students perform tasks because they are intrinsically related to an interesting or at least coherent goal, rather than for some extrinsic reason, like getting a good grade or pleasing the teacher. In reading and writing, for example, intrinsic motivation might be achieved by having students communicate with students in another part of the world by electronic mail (Collins, 1986; Levin, 1982).

4. *Exploiting cooperation* refers to having students work together in a way that fosters cooperative problem solving. Learning through cooperative problem solving is both a powerful motivator and a powerful mechanism for extending learning resources. In reading, activities to exploit cooperation might involve having students break up into pairs, where one student articulates his thinking process while reading and the other student questions the first student about why he made different inferences. Cooperation can be blended with competition; for example, individuals might work together in groups to compete with other groups.

CONCLUSION

Cognitive apprenticeship is not a model of teaching that gives teachers a packaged formula for instruction. Instead, it is an instructional paradigm for teaching. Cognitive apprenticeship is not a relevant model for all aspects of teaching. It does not make sense to use it to teach the rules of conjugation in French or to teach the elements of the periodic table. If the targeted goal of learning is a rote task, cognitive apprenticeship is not an appropriate model of instruction. Cognitive apprenticeship is a useful instructional paradigm when a teacher needs to teach a fairly complex task to students.

Cognitive apprenticeship does not require that the teacher permanently assume the role of the "expert" -in fact, we would imagine that the opposite should happen. Teachers need to encourage students to explore questions teachers cannot answer, to challenge solutions the "experts" have found-in short, to allow the role of "expert" and "student" to be transformed. Cognitive apprenticeship encourages the student to become the expert.

How might a teacher apply the ideas of cognitive apprenticeship in his or her classroom? We don't believe that there is a formula for implementing the activities of modeling, scaffolding and fading, and coaching. Ultimately, it is up to the teacher to identify ways in which cognitive apprenticeship can work in his or her own domain of teaching.

Apprenticeship is the way we learn most naturally. It characterized learning before there were schools, from learning one's language to learning how to run an empire. We have very successful models of how apprenticeship methods, in all their dimensions, can be applied to teaching the school curriculum of reading, writing, and mathematics. These models, and the framework we have developed, help point the way toward the redesign of schooling, so that students may better acquire true expertise and robust problem-solving skills, as well as an improved ability to learn throughout life.

ACKNOWLEDGMENTS

The work upon which this publication was based was supported in part by the Office of Educational Research and Improvement under Cooperative Agreement No. OEG 0087C 100 1, with the Reading Research and Education Center at the University of Illinois, Champaign-Urbana and Bolt Beranek and Newman Inc. It was also supported in part by the Institute for the Learning Sciences at Northwestern University, which was established in 1989 with the support of Andersen Consulting, part of The Arthur Andersen Worldwide Organization. The publication does not necessarily reflect the views of the agencies supporting the research. We thank Lauren Resnick for suggesting the writing of this paper, Susan Newman for her contributions to the original paper on cognitive apprenticeship, and Sharon Carver for developing the table summarizing the principles of cognitive apprenticeship.

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