CHAPTER 4

Cognitive Apprenticeship

Allan Collins

Throughout most of history, teaching and learning have been based on apprenticeship. Children learned how to speak, grow crops, construct furniture, and make clothes. But they didn't go to school to learn these things; instead, adults in their family and in their communities showed them how, and helped them do it. Even in modern societies, we learn some important things through apprenticeship: we learn our first language from our families, employees learn critical job skills in the first months of a new job, and scientists learn how to conduct world-class research by working side-by-side with senior scientists as part of their doctoral training. But for most other kinds of knowledge, schooling has replaced apprenticeship. The number of students pursuing an education has dramatically increased in the last two centuries, and it gradually became impossible to use apprenticeship on the large scale of modern schools. Apprenticeship requires a very small teacher-to-learner ratio, and this is not realistic in the large educational systems of modern industrial economies.

Even in modern societies, when someone has the resources and a strong desire to learn, they often hire a coach or tutor to teach them by apprenticeship – demonstrating that apprenticeship continues to be more effective even in modern societies. If there were some way to tap into the power of apprenticeship, without incurring the large costs associated with hiring a teacher for every two or three students, it could be a powerful way to improve schools. In the 1970s and 1980s, I was doing research at the intersection of education and new computer technology, and along with many other scholars, I was studying how this new technology could help us to transform schooling. Working with my colleague John Seely Brown, we began to believe that we could develop sophisticated computer-based learning environments that could provide students with apprenticeship-like experiences, providing the type of close attention and immediate response that has always been associated with apprenticeship.

From Traditional to Cognitive Apprenticeship

In her study of a tailor shop in Africa, Lave identified the central features of traditional apprenticeship (Lave, 1988). First, traditional apprenticeship focuses closely on the specific methods for carrying out tasks in a domain. Second, skills are instrumental to the accomplishment of meaningful real-world tasks, and learning is embedded in a social and functional context, unlike schooling, where skills and knowledge are usually abstracted from their use in the world. Apprentices learn domain-specific methods through a combination of what Lave called observation, coaching, and practice. In this sequence of activities, the apprentice repeatedly observes the master and his or her assistants executing (or modeling) the target process, which usually involves a number of different, but interrelated subskills. The apprentice then attempts to execute the process with guidance and help from the master (i.e., coaching). A key aspect of coaching is guided participation: the close responsive support which the master provides to help the novice complete an entire task, even before the novice has acquired every skill required. As the learner masters increasing numbers of the component skills, the master reduces his or her participation, providing fewer hints and less feedback to the learner. Eventually, the master fades away completely, when the apprentice has learned to smoothly execute the whole task.

Of course, most of us think of very traditional trades when we hear the term "apprenticeship" – like shoemaking or farming. John Seely Brown and I realized that the concept of apprenticeship had to be updated to make it relevant to modern subjects like reading, writing, and mathematics. We called this updated concept of apprenticeship "cognitive apprenticeship" to emphasize two issues (Brown, Collins, & Duguid, 1989; Collins, Brown, & Newman, 1989).

First, the term "apprenticeship" emphasized that cognitive apprenticeship was aimed primarily at teaching processes that experts use to handle complex tasks. Like traditional apprenticeship, cognitive apprenticeship emphasizes that knowledge must be used in solving real-world problems. Conceptual knowledge and factual knowledge are learned by being used in a variety of contexts, encouraging both a deeper understanding of the meaning of the concepts and facts themselves, and a rich web of memorable associations between them and the problem solving contexts. This dual focus on expert processes and learning in context are shared by both traditional apprenticeship and cognitive apprenticeship.

Second, "cognitive" emphasizes that the focus is on cognitive skills and processes, rather than physical ones. Traditional apprenticeship evolved to teach domains in which the process of carrying out target skills is externally visible, and thus readily available to both student and teacher for observation, comment, refinement, and correction, and the process bears a relatively transparent relationship to concrete products. But given the way that most subjects are taught and learned in school, teachers cannot make fine adjustments in students' application of skill and knowledge to problems and tasks, because they can't see the cognitive processes that are going on in students' heads. By the same token, students do not usually have access to the cognitive problem solving processes of instructors as a basis for learning through observation and mimicry. Before apprenticeship methods can be applied to learn cognitive skills, the learning environment has to be changed to make these internal thought processes externally visible. Cognitive apprenticeship is designed to bring these cognitive processes into the open, where students can observe, enact, and practice them.

There are two major differences between cognitive apprenticeship and traditional apprenticeship. First, because traditional apprenticeship is set in the workplace, the problems and tasks that are given to learners arise not from pedagogical concerns, but from the demands of the workplace. Because the job selects the tasks for students to practice, traditional apprenticeship is limited in what it can teach. Cognitive apprenticeship differs from traditional apprenticeship in

that the tasks and problems are chosen to illustrate the power of certain techniques and methods, to give students practice in applying these methods in diverse settings, and to increase the complexity of tasks slowly, so that component skills and models can be integrated. In short, tasks are sequenced to reflect the changing demands of learning.

Second, whereas traditional apprenticeship emphasizes teaching skills in the context of their use, cognitive apprenticeship emphasizes generalizing knowledge so that it can be used in many different settings. Cognitive apprenticeship extends practice to diverse settings and articulates the common principles, so that students learn how to apply their skills in varied contexts.

A Framework for Cognitive Apprenticeship

Cognitive apprenticeship focuses on four dimensions that constitute any learning environment: content, method, sequencing, and sociology (see Table 4.1, taken from Collins, Hawkins, & Carver, 1991).

Content

Recent cognitive research has begun to differentiate the types of knowledge required for expertise. Of course, experts have to master the explicit concepts, facts, and procedures associated with a specialized area – what researchers call *domain knowledge*. Domain knowledge includes the concepts, facts, and procedures explicitly identified with a particular subject matter. This is the type of knowledge that is generally found in school textbooks, class lectures, and demonstrations. Examples of domain knowledge in reading are vocabulary, syntax, and phonics rules.

Domain knowledge is necessary but not sufficient for expert performance. It provides insufficient clues for many students about how to solve problems and accomplish tasks in a domain. Psychologists have recently been trying to explicate the *tacit knowledge* that supports people's ability to make use of these concepts, facts, and procedures to solve real-world problems (also see Bransford et al., this volume). I call this second kind of knowledge *strategic knowledge*. Research has identified three kinds of strategic knowledge:

1. *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). In mathematics, a heuristic for solving problems is to try to find a solution for simple cases and see if the solution generalizes.
2. *Control strategies*, or *metacognitive strategies*, control the process of carrying out a task. 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 it might be best to reread parts of the text.
3. *Learning strategies* are strategies for learning domain knowledge, heuristic strategies, and control strategies. 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 learn to analyze others' texts for strengths and weaknesses.

Table 4.1. 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	
	Increasing complexity	meaningful tasks gradually increasing in difficulty
	Increasing diversity	practice in a variety of situations to emphasize broad application
	Global to local skills	focus on conceptualizing the whole task before executing the parts
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

Method

Teaching methods that emphasize apprenticeship give students the opportunity to observe, engage in, and invent or discover expert strategies in context. The six teaching methods associated with cognitive apprenticeship fall roughly into three groups. The first three methods (modeling, coaching, and scaffolding) are the core of traditional apprenticeship. They are designed to help students acquire an integrated set of skills through processes of observation and guided practice. The next two methods (articulation and reflection) are methods designed to help students 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 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. For example, a teacher might model the reading process by reading aloud in one voice, while verbalizing her thought processes in another voice (Collins & Smith, 1982). In mathematics, Schoenfeld (1985) 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, challenges, scaffolding, feedback, modeling, reminders, and new tasks aimed at bringing their performance closer to expert performance. Coaching is related to specific events or problems that arise as the student attempts to accomplish the task. In Palincsar and Brown's (1984) 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. Coaching refers broadly to all the different ways that coaches foster learning, whereas scaffolding refers more narrowly to the supports provided to the learner. These supports can take either the form of suggestions or help, as in Palincsar and Brown's (1984) reciprocal teaching, or they can take the form of physical supports, as with the cue cards used by Scardamalia, Bereiter, and Steinbach (1984) to facilitate writing, or the short skis used to teach downhill skiing (Burton, Brown, & Fischer, 1984). *Fading* involves the gradual removal of supports until students are on their own.
4. *Articulation* includes any method of getting students to explicitly state their knowledge, reasoning, or problem solving processes in a domain. Inquiry teaching (Collins & Stevens, 1983) is a strategy of questioning students to lead them to articulate and refine their understanding. Also, teachers can encourage students to articulate their thoughts as they carry out their problem solving, or have students assume the critic or monitor role in cooperative activities in order to articulate their ideas to other students. For example, an inquiry teacher in reading might question students about why one summary of the text is good but another is poor, in order to get them to formulate an explicit model of a good summary.
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. Some form of "abstracted replay," in which the critical features of expert and student performance are highlighted, is desirable (Collins & 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 guiding students to a mode of problem solving on their own. Enabling 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 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, the teacher might send the students to the library to investigate and write about theories as to why the dinosaurs disappeared.

Sequencing

Cognitive apprenticeship provides some principles to guide the sequencing of learning activities.

1. *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 (Burton, Brown, & Fischer, 1984; White, 1984). For example, in reading increasing task complexity might consist of progressing from relatively short texts, with simple syntax and concrete description, to texts in which complexly interrelated ideas and the use of abstractions make interpretation more difficult.

2. *Increasing diversity* refers to the construction of a sequence of tasks in which a wider and wider variety of strategies or skills are required. 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 mathematics, task diversity might be attained by intermixing very different types of problems, such as asking students to solve problems that require them to use a combination of algebraic and geometric concepts and techniques.
3. *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 before attending to the details of the terrain (Norman, 1973). Having a clear conceptual model of the overall activity helps learners make sense of the portion that they are carrying out, thus improving their ability to monitor their own progress and to develop attendant self-correction skills. In algebra, for example, computers might carry out low-level computations – the local skills – so that students can concentrate on the global structure of the task, and the higher order reasoning and strategies required to solve a complex, authentic problem.

Sociology

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 real-world 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. These considerations suggest several characteristics affecting the sociology of learning.

1. *Situated learning*. A critical element in fostering learning is having students carry out tasks and solve problems in an environment that reflects the nature of such tasks in the world (Brown, Collins, & Duguid, 1989; Lave & Wenger, 1991). 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 (Lave & Wenger, 1991; Wenger, 1998). Such a community leads to a sense of ownership, characterized by personal investment and mutual dependency. It cannot 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 in discussing how they interpret particularly difficult texts.
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) discuss the importance of creating learning environments in which students perform tasks because they are intrinsically related to a goal of interest to them, 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.

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.

Themes in Research on Cognitive Apprenticeship

In the years since cognitive apprenticeship was first introduced, there has been extensive research toward developing learning environments that embody many of these principles. Several of these principles have been developed further; in particular, situated learning, communities of practice, communities of learners, scaffolding, articulation, and reflection.

Situated Learning

Goal-based scenarios (Schank et al., 1994, Nowakowski, et al., 1994) embody many of the principles of cognitive apprenticeship. They can be set either in computer-based environments or naturalistic environments. Learners are given real-world tasks and the scaffolding they need to carry out such tasks. For example, in one goal-based scenario learners are asked to advise married couples as to whether their children are likely to have sickle-cell anemia, a genetically linked disease. In order to advise the couples, learners must find out how different genetic combinations lead to the disease and run tests to determine the parents' genetic makeup. There are scaffolds in the system to support the learners, such as various recorded experts who offer advice. Other goal-based scenarios support learners in a wide variety of challenging tasks, such as putting together a news broadcast, solving an environmental problem, or developing a computer-reservation system. Goal-based scenarios make it possible to embed cognitive skills and knowledge in the kinds of contexts where they are to be used. So people learn not only the basic competencies they will need, but also when and how to apply these competencies.

Video and computer technology has enhanced the ability to create simulation environments where students are learning skills in context. A novel use of video technology is the Jasper series developed by the Cognition and Technology Group (1997) at Vanderbilt University to teach middle-school mathematics. In a series of fifteen to twenty minute videos, students are put into various problem-solving contexts: for example, deciding on a business plan for a school fair or a rescue plan for a wounded eagle. The problems are quite difficult to solve and reflect the complex problem solving and planning that occurs in real life. Middle-school students work in groups for several days to solve each problem. Solving the problems results in a much richer understanding of the underlying mathematical concepts than the traditional school-mathematics problems.

These kinds of situated-learning tasks are different from most school tasks, because school tasks are decontextualized. Imagine learning tennis by being told the rules and practicing the forehand, backhand, and serve without ever playing or seeing a tennis match. If tennis were taught that way, it would be hard to see the point of what you were learning. But in school, students are taught algebra and Shakespeare without

being given any idea of how they might be useful in their lives. That is not how a coach would teach you to play tennis. A coach might first show you how to grip and swing the racket, but very soon you would be hitting the ball and playing games. A good coach would have you go back and forth between playing games and working on particular skills – combining global and situated learning with focused local knowledge. The essential idea in situated learning is to tightly couple a focus on accomplishing tasks with a focus on the underlying competencies needed to carry out the tasks.

Communities of Practice

Lave and Wenger (1991; Wenger, 1998) have written extensively about communities of practice and how learning takes place in these contexts. They introduced the notion of *legitimate peripheral participation* to describe the way that apprentices participate in a community of practice. They described four cases of apprenticeship and emphasized how an apprentice's identity derives from becoming part of the community of workers, as they become more central members in the community. They also noted that an apprenticeship relationship can be unproductive for learning, as in the case of the meat cutters they studied, where the apprentices worked in a separate room and were isolated from the working community. Productive apprenticeship depends on opportunities for apprentices to participate legitimately in the community practices that they are learning.

The degree to which people play a central role and are respected by other members of a community determines their sense of identity (Lave & Wenger, 1991). The central roles are those that most directly contribute to the collective activities and knowledge of the community. The motivation to become a more central participant in a community of practice can provide a powerful incentive for learning. Frank Smith (1988) argues that children will learn to read and write if the people they admire read and write. That is, they will want to join the "literacy club" and will work hard to become members. Learning to read is part of becoming the kind of person they want to become. Identity is central to deep learning.

Wenger (1998) argues that people participate in a variety of communities of practice – at home, at work, at school, and in hobbies. In his view a community of practice is a group of people participating together to carry out different activities, such as garage bands, ham-radio operators, recovering alcoholics, and research scientists. "For individuals, it means that learning is an issue of engaging in and contributing to the practices of their communities. For communities, it means that learning is an issue of refining their practice and ensuring new generations of members. For organizations, it means that learning is an issue of sustaining the interconnected communities of practice through which an organization knows what it knows and thus becomes effective and valuable as an organization" (pp. 7–8).

Communities of Learners

In recent years there has developed a "learning communities" approach to education that builds on Lave and Wenger's (1991) notion of a community of practice. In a learning community the goal is to advance the collective knowledge and in that way to support the growth of individual knowledge (Scardamalia & Bereiter, 1994, this volume). The defining quality of a learning community is that there is a culture of learning, in which everyone is involved in a collective effort of understanding (Brown & Campione, 1996).

There are four characteristics that a learning community must have (Bielaczyc & Collins, 1999): (1) diversity of expertise among its members, who are valued for their contributions and given support to develop; (2) a shared objective of continually advancing the collective knowledge and skills; (3) an emphasis on learning how to learn; and (4) mechanisms for sharing what is learned. It is not necessary that each member assimilate everything that the community knows, but each should know who

within the community has relevant expertise to address any problem. This marks a departure from the traditional view of schooling, with its emphasis on individual knowledge and performance, and the expectation that students will acquire the same body of knowledge at the same time.

Brown and Campione (1996) have developed a model they call Fostering a Community of Learners (FCL) for grades 1–8. The FCL approach promotes a diversity of interests and talents, in order to enrich the knowledge of the classroom community as a whole. The focus of FCL classrooms is on the subject areas of biology and ecology, with central topics such as endangered species and food chains and webs. There is an overall structure of students (1) carrying out research on the central topics in small groups where each student specializes in a particular subtopic area, (2) sharing what they learn with other students in their research group and in other groups, and (3) preparing for and participating in some "consequential task" that requires students to combine their individual learning, so that all members in the group come to a deeper understanding of the main topic and subtopics. Teachers orchestrate students' work, and support students when they need help.

In the FCL model there are usually three research cycles per year. A cycle begins with a set of shared materials meant to build a common knowledge base. Students then break into research groups that focus on a specific research topic related to the central topic. For example, if the class is studying food chains, then the class may break into five or six research groups that each focus on a specific aspect of food chains, such as photosynthesis, consumers, energy exchange, and so on. Students research their subtopic as a group and individually, with individuals "majoring" by following their own research agendas within the limits of the subtopic. Students also engage in regular "cross-talk" sessions, where the different groups explain their work to the other groups, ask and answer questions, and refine their understanding. The research activities include reciprocal teaching (Palincsar & Brown, 1984), guided writing and composing, consultation with subject matter experts outside the classroom, and cross-age tutoring. In the final part of the cycle, students from each of the subtopic groups come together to form a "jigsaw" group (Aronson, 1978) in order to share learning on the various subtopics and to work together on some consequential task. In the jigsaw, all pieces of the puzzle come together to form a complete understanding. The consequential tasks "bring the research cycle to an end, force students to share knowledge across groups, and act as occasions for exhibition and reflection" (Brown & Campione, 1996, p. 303).

A key idea in the learning-communities approach is to advance the collective knowledge of the community, and in that way to help individual students learn. This is directly opposed to the approaches found in most schools, where learning is viewed as an individual pursuit and the goal is to transmit the textbook's and teacher's knowledge to students. The culture of schools often discourages sharing of knowledge – by inhibiting students from talking, working on problems or projects together, and sharing or discussing their ideas. Testing and grading are administered individually. When taking tests, students are prevented from relying on other resources, such as other students, books, or computers. The whole approach is aimed at ensuring that individual students have all the knowledge in their heads that is included in the curriculum. Thus, the learning-community approach is a radical departure from the theory of learning and knowledge underlying schooling.

Scaffolding

Computer-based, interactive learning environments can be designed to offer support to learners in various guises, so that students can tackle complex, difficult tasks. Scaffolding is the support a system provides to learners as they carry out different activities (Wood, Bruner, & Ross, 1976). This can take the form of structured or highly constrained tasks, help systems that give advice

when the learner does not know what to do or is confused, guided tours on how to do things, hints when needed, and so on. One form that scaffolding takes is that the system can do many of the low-level chores, such as arithmetic calculations, while the learner concentrates on the higher-level task of deciding what to do. Another form is that the system can provide an overall structure that allows completion of a complex task, guiding students to individual components of the task, and showing them how each component fits into the overall task. Scaffolding helps learners carry out tasks that are beyond their capabilities. Quintana et al. (2004) suggest twenty specific strategies for designing scaffolds to support sense making, inquiry, articulation, and reflection in computer-based learning environments. In most situations, scaffolding naturally *fades* as learners are able to accomplish tasks on their own.

In an analysis of computer-based learning environments, Reiser (2004) points out that most of the work on scaffolding has focused on *structuring* the task for students, in order to make it easier for learners to accomplish the task. But he emphasizes that there is another important role for scaffolding – *problematizing* the student's performance, or explicitly questioning the key content and strategies used during the task, so that students reflect more on their learning. Although this may make the task more difficult, it can facilitate learning.

Bruner based his concept of scaffolding on Vygotsky's (1978) notion of the *zone of proximal development*, which described how adults can support learners to accomplish tasks that they cannot accomplish on their own. Hence, the focus of research on scaffolding (see for example Davis and Miyake, 2004) has been on supporting individuals in their learning. But Kolodner et al. (2003) point out that it is important to scaffold groups as well as individuals. So, for example, in their work teaching science, they first provide students with focused collaboration activities to solve simple problems, which they call "launcher units." Engaging in these activities and reflecting on them helps students to collaborate more effectively and to understand the value of collaboration.

In schools, needing to ask for extra help often implies that the student is inferior, so students are reluctant to ask for help. When scaffolding is provided by computers, it comes without criticism and without others knowing that the student needed help. Computers offer a kind of scaffolding that avoids stigmatization and provides individualized instructional support.

Articulation

In order to abstract learning from particular contexts, it is important to articulate one's thinking and knowledge, so that it becomes available in other contexts. There have been several successful examples of how effective group discussions can be in classrooms. For example, Lampert (Lampert, Rittenhouse, & Crumbaugh, 1996) showed how fifth grade children can form a community of inquiry about important mathematical concepts. She engaged students in discussion of their conjectures and interpretations of each other's reasoning. Techniques of this kind have been successful with even younger children (Cobb & Bauersfeld, 1995) and may partly underlie the success of Japanese mathematical education (Stigler & Hiebert, 1999).

A notable method for fostering articulation in science is the Itakura method developed in Japan (Hatano & Inagaki, 1991). First, students make different predictions about what will happen in a simple experiment, where they are likely to have different expectations. For example, one experiment involves lowering a clay ball into water and predicting what will happen. After students make their initial predictions, they discuss and defend among themselves why they think their predictions are correct. After any revisions in their predictions, the experiment is performed and discussion ensues as to why the result came out the way it did.

Sandoval and Reiser (2004) have developed a computer system called the Biology Guided Inquiry Learning Environment (BGuILE) that supports students in making

scientific arguments in the context of population genetics. The system presents the students with a mystery of why many of the finches in the Galapagos Islands died during a period of drought (see Edelson & Reiser, this volume). In order to solve the mystery, students have to analyze extensive data that were collected by scientists and come up with a reasoned conclusion as to why some finches died while others survived. The Explanation Constructor tool in the system prompts the students to put in all the pieces of a sound genetics-based argument, after they have decided what caused the finches to die. Hence, the system scaffolds students to articulate their argument in a much more explicit form than they would normally do.

The Knowledge Forum environment developed by Scardamalia and Bereiter (this volume; 1994) is an environment where students articulate their ideas in writing over a computer network. The model involves students investigating problems in different subject areas over a period of weeks or months. As students work, they enter their ideas and research findings as notes in an online knowledge base. The software scaffolds students in constructing their notes through features such as theory-building scaffolds (e.g., "My Theory," "I Need to Understand") or debate scaffolds (e.g., "Evidence For"). Students can read through the knowledge base, adding text, graphics, questions, links to other notes, and comments on each other's work. When someone has commented on another student's work, the system automatically notifies them about it. The central activity of the community is contributing to the communal knowledge base. Contributions can take the form of (a) *individual notes*, in which students state problems, advance initial theories, summarize what needs to be understood in order to progress on a problem or to improve their theories, provide a drawing or diagram, and so on; (b) *views*, in which students or teachers create graphical organizations of related notes; (c) *build-ons*, which allow students to connect new notes to existing notes; and (d) *"Rise Above It" notes*, which synthesize notes in the knowledge base. Any of these kinds of contributions can be jointly authored. The goal is to engage students in progressive knowledge building, where they continually develop their understanding through problem identification, research, and community discourse. The emphasis is on progress toward collective goals of understanding, rather than individual learning and performance.

Reflection

Reflection encourages learners to look back on their performance in a situation, and compare their performance to other performances, such as their own previous performances and those of experts. Reflection has received much attention as a vital aspect of the learning process for both children and adults. Schon (1983) describes how systematic reflection on practice is critical for many professionals engaged in complex activities. Designers of learning environments often build supports for reflection into tasks by asking students to discuss and reflect upon the strategies used to guide their actions. Reflection can highlight the critical aspects of a performance and encourage learners to think about what makes for a good performance and how they might improve in the future.

There are three forms that reflection can take, all of which are enhanced by technology: (1) reflection on your process, (2) comparison of your performance to that of others, and (3) comparison of your performance to a set of criteria for evaluating performances:

- *Reflection on your process*: Because technology makes it possible to record performances, people can look back at how they did a task. One useful form of reflection is an "abstracted replay," where the critical decisions made are replayed. A system that teaches complex problem solving could allow learners to compare their decisions in solving a complex problem to an expert solution, so that they can see how they might have done better.

- *Comparison of your performance to that of others*: One of the most effective ways that people learn is by comparing different performances, including their own, to determine what factors lead to success. This is called "perceptual learning" (Bransford et al., 1989). Technology makes it possible to record different performances that learners can then analyze.
- *Comparison of your performance to a set of criteria for evaluating performances*: One of the most effective ways to improve performance is to evaluate how you did with respect to a set of criteria that determine good performance. For example, White and Frederiksen (1998) showed that students who evaluated their performance on projects using a set of eight criteria improved much more than students who carried out the same tasks, but did not reflect on their performance in the same way. In fact this reflection helped the weaker students much more than the stronger students.

The essential way people get better at doing things is by thinking about what they are going to do beforehand, by trying to do what they have planned, and by reflecting back on how well what they did came out. If they can articulate criteria for evaluating what they did, this will help them as they plan what to do on the next cycle. The wide availability of computers and other recording technologies makes performances easier to produce and to reflect on. For example, students can now produce their own news broadcasts, musical performances, or plays, either on audiotape, videotape, or cable television, and send them to other schools or to parents. Furthermore, they can play these back, reflect upon them, and edit them until they are polished. One of the best examples of the use of technology for recording performances has been in Arts Propel (Gardner, 1991) with its cycle of performing, reflecting upon the performance in terms of a set of criteria, and then performing again. Most educational practice has not recognized the power of this learning-cycle approach.

Conclusion

As these examples illustrate, there has been extensive research over the last fifteen years that has incorporated the principles of cognitive apprenticeship in the design of learning environments. As computer-based learning environments become more pervasive, there is likely to be continued development of new ways to embody these principles in their design.

References

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

Bielaczyc, K., & Collins, A. (1999) Learning communities in classrooms: A reconceptualization of educational practice. In C. M. Reigeluth (Ed.): *Instructional-design theories and models: A new paradigm of instructional theory* (pp. 269–292). Mahwah, NJ: Lawrence Erlbaum Associates.

Bransford, J. D., Franks, J. J., Vye, N. J., & Sherwood, R. D. (1989). New approaches to instruction: Because wisdom can't be told. In S. Vosniadou & A. Ortony (Eds.), *Similarity and analogical reasoning* (pp. 470–497). New York: Cambridge University Press.

Brown, A., & Campione, J. (1996). Psychological theory and the design of innovative learning environments: On procedures, principles, and systems. In L. Schauble & R. Glaser (Eds.) *Innovations in learning: New environments for education* (pp. 289–325). Mahwah, NJ: Lawrence Erlbaum Associates.

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher*, *18*(1), 32–42.

Burton, R., Brown, J. S., & Fischer, G. (1984). Skiing as a model of instruction. In B. Rogoff and J. Lave (Eds.), *Everyday cognition: Its developmental and social context* (pp. 139–150). Cambridge, MA: Harvard University Press.

Chi, M. T. H., Bassok, M., Lewis, M. W., Reimann, P., & Glaser, R. (1989). Self-Explanations: How students study and use examples in learning to solve problems. *Cognitive Science*, *13*, 145–182.

Cobb, P., & Bauersfeld, H. (Eds.) (1995). *The emergence of mathematical meaning: Interaction*

in classroom cultures. Mahwah, NJ: Lawrence Erlbaum Associates.

Cognition and Technology Group at Vanderbilt (1997). *The Jasper Project: Lessons in curriculum, instruction, assessment, and professional development*. Mahwah, NJ: Lawrence Erlbaum Associates.

Collins, A., & Brown, J. S. (1988). The computer as a tool for learning through reflection. In H. Mandl and A. Lesgold (Eds.), *Learning issues for intelligent tutoring systems* (pp. 1–18). New York: Springer.

Collins, A., Brown, J. S., & Newman, S. E. (1989). Cognitive apprenticeship: Teaching the craft of reading, writing, and mathematics. In L. B. Resnick (Ed.), *Knowing, learning, and instruction: Essays in honor of Robert Glaser* (pp. 453–494). Hillsdale, NJ: Lawrence Erlbaum Associates.

Collins, A., Hawkins, J., & Carver, S. M. (1991). A cognitive apprenticeship for disadvantaged students. In B. Means, C. Chelemer & M. S. Knapp (Eds.) *Teaching advanced skills to at-risk students*. (pp. 216–243). San Francisco: Jossey-Bass.

Collins, A., & Smith, E. E. (1982). Teaching the process of reading comprehension. In D. K. Detterman & R. J. Sternberg (Eds.), *How much and how can intelligence be increased?* (pp. 173–185). Norwood, NJ: Ablex.

Collins, A., & Stevens, A. L. (1983). A cognitive theory of interactive teaching. In C. M. Reigeluth (Ed.), *Instructional design theories and models: An overview* (pp. 247–278). Hillsdale, NJ: Lawrence Erlbaum Associates.

Cuban, L. (1984). *How teachers taught*. New York: Longman.

Davis, E. A., & Miyake, N. (Eds.) (2004). Special issue: Scaffolding. *Journal of the Learning Sciences*, *13(3)*, 265–451.

Gardner, H. (1991) Assessment in context: The alternative to standardized testing. In B. Gifford & C. O'Connor (Eds.), *Future assessments: Changing views of aptitude, achievement, and instruction* (pp. 77–120). Boston: Kluwer.

Hatano, G., & Inagaki, K. (1991) Sharing cognition through collective comprehension activity. In: L. Resnick, J. Levin, & S. D. Teasley (Eds.), *Perspectives on socially shared cognition* (pp. 331–348). Washington, DC: American Psychological Association.

Kolodner, J. L., Crismond, D., Fasse, B. B., Gray, J. T., Holbrook, J., Ryan, M., & Puntambekar, S. (2003). Problem-based learning meets case-based reasoning in the middle-school science classroom: Putting a Learning-by-Design curriculum into practice. *Journal of the Learning Sciences, 12*(4), 495–548.

Lampert, M., Rittenhouse, P., & Crumbaugh, C. (1996). Agreeing to disagree: Developing sociable mathematical discourse. In D. Olson & N. Torrance (Eds.), *Handbook of education and human development* (pp. 731–764). Oxford: Blackwell's Press.

Lave, J. (1988). The culture of acquisition and the practice of understanding (Report No. IRL88-0007). Palo Alto, CA: Institute for Research on Learning.

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

Lepper, M. R., & Greene, D. (1979). *The hidden costs of reward*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Norman, D. A. (1973). Memory, knowledge, and the answering of questions. In R. L. Solso (Ed.), *Contemporary issues in cognitive psychology: The Loyola symposium* (pp. 135–165). Washington, DC: Winston.

Nowakowski, A., Campbell, R., Monson, D. Montgomery, J., Moffett, C., Acovelli, M., Schank, R., & Collins, A. (1994). Goal-based scenarios: A new approach to professional education. *Educational Technology*, *34*(9), 3–32.

Palincsar, A. S., & Brown, A. L. (1984). Reciprocal teaching of comprehension-fostering and monitoring activities. *Cognition and Instruction*, *1*(2), 117–175.

Quintana, C., Reiser, B. J., Davis, E. A., Krajcik, J., Fretz, E., Duncan, R. G., Kyza, E., Edelson, D., & Soloway, E. (2004). A scaffolding design framework fo software to support science inquiry. *Journal of the Learning Sciences*, *13*(3), 337–386.

Reiser, B. J. (2004). Scaffolding complex learning: The mechanisms of structuring and problematizing student work. *Journal of the Learning Sciences*, *13*(3), 273–304.

Sandoval, W. A., & Reiser, B. J. (2004). Explanation-driven inquiry: Integrating conceptual and epistemic scaffolds for scientific inquiry. *Science Education*, *88*, 345–372.

Scardamalia, M., & Bereiter, C. (1994). Computer support for knowledge-building communities. *Journal of the Learning Sciences*, *3*(3), 265–283.

Scardamalia, M., Bereiter, C., & Steinbach, R. (1984). Teachability of reflective processes in written composition. *Cognitive Science*, 8, 173–190.

Schank, R. C., Fano, A., Bell, B., & Jona, M. (1994) The design of goal-based scenarios. *Journal of the Learning Sciences*, 3(4), 305–346.

Schoenfeld, A. H. (1985). *Mathematical problem solving*. Orlando, FL: Academic Press.

Schon, D. A. (1983). *The reflective practitioner: How professionals think in action*. New York: Basic Books.

Smith, F. (1988). *Joining the literacy club*. Portsmouth, NH: Heinemann.

Stigler, J., & Hiebert, J. (1999). *The teaching gap: Best ideas from the world's teachers for improving education in the classroom*. New York: Free Press.

Vygotsky, L. S. (1978). *Mind in society: The development of higher mental processes*. (M. Cole, V. John-Steiner, S. Scribner, & E. Souberman, Eds.) Cambridge, MA: Harvard University Press.

Wenger, E. (1998). *Communities of practice: Learning, meaning, and identity*. New York: Cambridge University Press.

White, B. Y. (1984). Designing computer games to help physics students understand Newton's laws of motion. *Cognition and Instruction*, 1(1), 69–108.

White, B. Y., & Frederiksen, J. R. (1998). Inquiry, modeling, and metacognition: Making science accessible to all students. *Cognition and Instruction*, 16(1), 3–118.

Wood, D., Bruner, J., & Ross, G. (1976). The role of tutoring in problem solving. *Journal of Child Psychology and Psychiatry*, 17, 89–100.