

RESEARCH WATCH

Cognitive Apprenticeship: Teaching Inside Out

"Cognitive Apprenticeship: Teaching the Crafts of Reading, Writing, and Mathematics."

Allan Collins, John Seely Brown, Susan E. Newman in *Knowing, Learning, and Instruction: Essays in Honor of Robert Glaser*, ed. Lauren Resnick (Lawrence Erlbaum, 1989) pp. 453-494.

PAST EFFORTS TO UNDERSTAND and improve teaching have sometimes focused too largely on externals. Advice on modulating one's voice, on moving out from behind the lectern has its utility, but it's also a bit like treating the symptoms of a cold without recommending the wisdom of bed rest. One can hardly blame faculty who remain skeptical of efforts to help them teach more effectively that do not demonstrate—and help them form in their own minds—a more sophisticated understanding of the dynamics of teaching and learning.

The relatively new field of cognitive science appears to be developing that understanding. Many efforts to improve teaching have turned to the rhetoric of effective public speaking, focusing on the classroom as a kind of theater. The leading edge in cognitive research, however, suggests that the rhetoric of thinking may offer a better pattern. By externalizing both the inner discourse of expert or faculty thinking and the inner dialogue of student or novice thinking, cognitive psychologists say, faculty can show students "how to do it" in any discipline instead of merely telling them about the facts they've learned that students ought to know.

Currently, a body of recent research in teaching and learning has been pulled together in a comprehensive

model called "cognitive apprenticeship." The model is creating considerable interest among teaching and learning specialists not only because it demonstrates how the research fits together into an integrated pattern, but also because it shows this pattern being applied in three vivid portraits of actual teaching situations—teaching reading, college mathematics, and writing.

Ironically, the newness of cognitive apprenticeship lies in the rediscovery of an older way of teaching. Only in the last century, and only in industrialized countries, the developers of the model point out, has schooling replaced apprenticeship as the most common means of learning. Indeed, Allan Collins, chief author of the model, points out that it was not that long ago that medical education shifted away from an emphasis on learning the art of diagnosis in grand rounds and toward more classroom science instruction.

Something was lost, especially in undergraduate education, in the move toward didactic teaching and away from a learning environment dependent on observation, coaching, and successive approximation. Can what was lost be regained? Perhaps; especially if faculty realize that in conveying information and concepts about their subjects, they may only be telling students the half of it, the cognitive versus the metacognitive half, as a learning theorist might say.

A focus on content can leave key aspects of what faculty do inside their own minds invisible to students. Yet it's the internal processes faculty engage in in acquiring knowledge and carrying out complex tasks in their fields that students need to see if they're to gain understanding and share the excitement of different intellectual disciplines. In a sense faculty need to learn to think out loud, to externalize the processes they usually carry out internally.

Moreover, faculty need to have students think out loud as well. "It's amazing," says Collins, "teachers don't ever hear the thinking of students as they're trying to solve problems. They don't understand *how* students understand and typically they way overestimate what they've grasped." The aim of the cognitive apprenticeship model, he says, "is to get the thinking

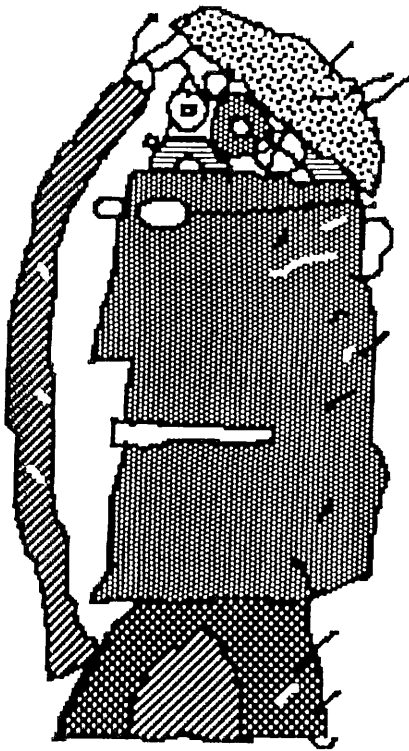
process out into the space between teachers and students where they can both see it."

Developing a conscious awareness of how one's mind operates and the kinds of knowledge it uses is the first step in discovering how to share what one really knows. For faculty, that step leads directly to a second, in which they understand the value of different teaching methods, seeing them not as performance tricks, but as echoes and extensions of their own mental processes.

Cognitive researchers describe the content of expert knowledge as falling into four main categories:

1. **Domain knowledge** includes the facts, dates, formulas, and basic concepts of a particular discipline. It's the material covered in textbooks and class lectures. But learned apart from realistic problems and the kinds of expert problem-solving strategies that faculty carry around unconsciously, domain knowledge tends to remain "inert" even in good students, say Collins and his colleagues.
2. **Heuristic strategies** are the "tricks of the trade" or general approaches to material that have proved valuable in the past, but which don't always work. For example, planning to rewrite the beginning of an essay so that it fits the final product is a standard heuristic strategy in writing.
3. **Control strategies** describe the process of knowing which trick of the trade to try first and when to drop that strategy and try a different one. They represent an expert's knowledge about how to manage the thinking process. They imply an on-going monitoring, diagnosing and correcting of one's own thinking.
4. **Learning strategies** are, in a sense, the sum of the other three types of knowledge. They are the knowledge an expert develops about how to learn.

Understanding the strategies of expert practice, say Collins and his colleagues, "depends crucially on understanding the way they are embedded in the context of actual problem solving." Thus, they admit, not all the strategies necessary in



complex learning can be captured and made explicit.

However, their research has found that master teachers convert students from audience members into apprentices by externalizing their expertise using these basic methods:

1. **Modeling**—performing a mental task in front of students in such a way that they are able to observe the processes needed to perform it and thus form a conceptual model of their own, one which includes heuristic and control strategies as well as domain knowledge.

An exciting example reported by Collins and his colleagues describes Prof. Alan Schoenfeld of the University of Rochester (who has written a good bit on teaching problem solving) working a math problem with two polynomials with “reversed” coefficients.

Schoenfeld’s open thinking for the students runs like this: “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.” After solving the problem, Schoenfeld does a postmortem, examining the thought process and focusing on the points where breakthroughs occurred.

Sometimes strategies failed, and he met dead ends. That’s important, Collins believes, because it helps students develop a belief in their own capacities. Seeing an expert struggle assures them that they aren’t the only ones who flounder about and have to start over.

2. **Coaching**—observing students dealing with problems or texts and offering hints and guidance aimed at directing them toward expert performance. The faculty member puts down the burden of dispensing facts and concentrates instead on monitoring and diagnosing what students are doing with them, raising questions they may not have thought of or reminding them of overlooked aspects of the problem.

3. **Scaffolding**—closely related to coaching, scaffolding describes the support master teachers give students to help them carry out assigned tasks. The emphasis here, however, falls on an accurate diagnosis of students’ current skill levels. The corollary of scaffolding is *fading*, the process of gradually withdrawing help and support as students become more adept.

4. **Articulation** refers to any means a faculty member uses to get students to self-consciously demonstrate their own thinking processes. “Which is the best summary of the novel and why?” a faculty member might ask, thus encouraging an understanding of critical process and the novel at the same time.

5. **Reflection** refers to methods that encourage students to compare their own thinking processes with experts, other students and eventually against their own internal model of expertise. Usually these methods involve “replaying” what a student has done either through a postmortem like the one the math professor performed on his own problem-solving or perhaps some activity using audio or video tape. Small group activity also generally encourages both reflection and articulation.

6. **Exploration** describes methods designed to push students beyond solving set problems. One of its chief aims in fact is moving students to a point where they are able to design their own problems within a given field and then solve them using the knowledge and cognitive skills they’ve acquired. Pushing students in this way forces them to realize that an important part of learning lies in reaching beyond what’s already known.

To be able to reach that far, students must have developed what one theorist calls a “belief system” along with a body of basic information and a rather nimble set of control strategies to

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“In some sense,” says Collins, “a lot of our expertise as professors is tacit. We’re unaware of it; we haven’t articulated it to ourselves. Cognitive apprenticeship is aimed at creating problem-solving situations that will exhibit it to students. The other half of it, of course, is that when we get students to articulate their thought processes and we are able to see how they differ from ours, then, whether we have a complete theory of expert practice or not, we can see what to do to put students back on course.”

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RESEARCH WATCH

Cognitive Apprenticeship II: Modeling Metacognition

RESearch shows that college mathematics faculty take three to four times as long to read a calculus problem before beginning to work on it than their students do. Why? What's going on inside their heads? Could that mental activity describe what one researcher calls the "hidden curriculum"—the aspects of knowing a subject that could be, but usually aren't, taught?

Why do students faced with the problem often grab the first idea that comes to them and cling to it—and only it—until time for solving the problem has run out?

Venerable adjectives like "wisdom" and "experience" cloak what's going on inside sage heads and almost suggest that it can only be grasped after years in the school of hard knocks. But the relatively new field of cognitive science (less than thirty years old) has begun to shed important light on the inner workings of this wisdom. The answers from cognitive scientists aren't as terse (or as didactic) as the carpenter's adage: "Measure twice; cut once." But they're more exciting and probably even more useful.

The premier issue of *The National Teaching and Learning Forum* profiled a synoptic research article by Collins, Brown and Newman (1989) called "Cognitive Apprenticeship: Teaching the Crafts of Reading, Writing, and Mathematics." Defining faculty as *experts* and students as *novices*, that article breaks expert knowledge into four categories:

- **Domain knowledge**—the basic facts, dates, formulas and concepts of a particular discipline
- **Heuristic strategies**—"tricks of the trade," general approaches to problems that experience has proven valuable, but not infallible

- **Control strategies**—a dynamic of engagement and reflection with the problem, an intuitive sense of knowing which trick of the trade to apply and when to give it up as unproductive
- **Learning strategies**—the sum of the other three when applied to a new field of study or new situation—that is to say, knowledge about how to learn both in general and in specific contexts.

If "expert practice" lies in successfully integrating cognitive and metacognitive practices (i.e. the knowing of the facts with the knowing of how to use them deftly), taking a novice under one's wing in a college classroom becomes largely a matter of externalizing or modeling the processes of thought faculty usually carry out not only internally, but invisibly. How much more would the calculus students learn if, after scratching his head four times longer than his students, the faculty member not only worked the problem on the board, but also thought his way through it out loud, including all the false starts that presented themselves, all the hunches and gut feelings he used in winding his way toward a solution? What if he even risked being unable to solve it? They'd learn a lot.

But how much more would they learn if the classroom experience for the entire semester were a "microcosm of mathematical culture," a place where the "society of mind" thrived on the practice of mathematics?

The cognitive apprenticeship model of Collins, *et al*, draws heavily on Professor Alan Schoenfeld's research on cognition and metacognition in mathematics (*Mathematical Problem Solving*, 1985; *etc.*) Since 1989, Schoenfeld's understanding of metacognition in the classroom has moved a step further. In *Handbook for Research on Mathematics Teaching and Learning* (D. Grouws, ed. Macmillan, 1992) he adds a fifth category—"practices"—which focuses on the importance of creating such cultures among students. Citing a colleague, Schoenfeld writes: "Becoming a good mathematical problem solver—becoming a good thinker in any domain—may be as much a matter of acquiring the habits and dispositions of interpretation and sense-making as of acquiring any

particular set of skills, strategies, or knowledge."

Schoenfeld's laboratory is his class in problem solving at the University of California—Berkeley, where he experiments with establishing what he calls "microcosms of selected aspects of mathematical culture." From day one, Schoenfeld immerses his students in a "socialization process" in which they come to understand that the habits and dispositions of good problem solving are as important as any facts or theorems.

"Mathematicians do mathematics because they love it," Schoenfeld explains, "and when you watch them doing mathematics, there's this tremendous feeling of engagement, at being at the end of their own understanding and being in the game, because what you do is stretch your own understanding, and you and the community gain by it." "It's a pleasurable, exploratory enterprise," he exclaims.

But, Schoenfeld continues, follow a mathematician from a morning in his office happily spent doing mathematics into the lecture hall. In that short walk something important is often lost. "What he does is stand up and 'talks' it at them in such a way that they're all passive recipients and have none of the pleasure of engagement that excites *him* about the mathematics," Schoenfeld says.

"There's something wrong in that process," he continues. "If all of these other things are part and parcel of what doing mathematics is—being at the edge of your confidence, but enjoying it; engaging in sense-making processes, rather than simply ingesting someone else's stuff—then those things ought to be part of the learning process for students as well. I mean if they're not, it will be the rare few who do it on their own outside the context of formal instruction and who become the survivors and ultimately the mathematicians."

So how does Schoenfeld keep from getting lost? How does he teach expert behavior based on what he's learned about students' cognitive processes and the metacognitive processes of faculty? How, for example, does he teach students not to fall in love with the first notion that occurs to them about how to solve a problem? "Telling doesn't do very much good," he says. Since telling

his class to avoid that trap doesn't do much good, he lets them see it for themselves. "One of the things I do is show the students videotapes of other students solving problems. I don't do it too frequently, but what happens is they can often be pretty dispassionate analysts of other people going off the deep end, and then recognize that the potential for doing the same resides within them too."

After one or two tapes, you've made your point, Schoenfeld has learned, and other techniques must press the advantage gained.

"Real-time interventions are a hell of a lot more powerful than general advice," he says, and that's where modeling and small group activity come in. "The very first day, I tell them it's going to be a main theme of the course, and they will spend somewhere between a third and half of their time the entire semester in small groups working problems, and roughly that amount of time in every class period."

Schoenfeld sees the first day as crucial to the success of the class. There, he

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establishes his authority as an expert and sets the ground rules for the mathematical culture he hopes to build. Again, he does these things through carefully staged experiences for the most part, rather than through a lot of firm telling. For example, on the first day, he hands out a set of problems which he knows from experience will stump students for at least a half hour, but which they'll likely be able to solve in about five minutes, once he gives them a few simple suggestions.

"The power of that [experience] is that they get to be convinced that I have something to teach them, which is really important," Schoenfeld explains, "because if I'm going to be putting them

through all this strange stuff, they've got to believe it's worth it." Understanding, confronting and altering students' belief systems is an important component in the cognitive apprenticeship model. But powerful experiences involve powerful risks, especially when they invade areas as closely tied to issues of self-esteem and worth as students' belief systems may be. Schoenfeld admits that if he's not very careful, students could end up being put off. "I can remember once when I inadvertently said something that alienated the whole class," Schoenfeld confesses. "It took me a month to get 'em back. There's certainly the potential for things like that." But handled carefully, students understand that they're being given an experience that exemplifies the value of having a variety of heuristic strategies to draw upon in solving problems.

Schoenfeld: "I put them through that experience and say 'Look, this is going to be a problem-solving course. You guys are going to spend a lot of time in class solving problems. We're going to have discussions about them, not only the mathematics, but also about how and why you solved them and what was useful and what wasn't. I'm going to be teaching you a lot of things, including some problem-solving strategies, but you're going to find this the most frustrating course that you've ever taken in your life, because every time you think you understand what's going on, I'm going to change the rules of the game."

"My goal for this course is to teach you to solve problems I haven't taught you how to solve."

And Schoenfeld reinforces that that's an attainable goal by telling his students stories about past classes who, in fact, solved problems he'd put on the final exam for the very reason that he didn't know how to solve them himself.

"That first day is deliberately staged to show them what they're in for," he says. "And that's a critically important part of the course; if that doesn't go right, then the whole course doesn't fly." He must awaken their interest and win their trust and, at the same time, show them, not only the need for engagement and reflection in problem solving, but the excitement of it as well.

But the real excitement of Schoenfeld's research lies in its implications for more effective teaching across the board. "The dimensions of analysis (heuristics, for example) are relevant and appropriate for any problem-solving domain," Schoenfeld believes. And he says, "Virtually any domain where you are trying to do something significant, I can consider a problem-solving domain." To illustrate the point he draws analogies with writing and cites important cognitive research done not only in teaching writing, but in teaching history and literature as well.

"Strategies control beliefs," says Schoenfeld; so that, while there are heuristics or metacognitive dimensions to every discipline, certain problem-solving strategies tend to be specific to each domain. "The strategies that work in mathematics are not the same strategies that work in writing, for example."

However, the patterns or strategies of successful control of the problem-solving process—of higher order thinking—tend to be "domain-independent." The same qualities of balance, of alternatively engaging and reflecting upon problems, that allow one to develop expertise in mathematics are the same qualities that make an effective writer—or historian or chemist—Schoenfeld believes. "What's really needed in my opinion," says Schoenfeld, "is a research program in different domains to identify those [domain-specific metacognitive strategies] at a level where they can be taught. I'm reasonably confident that, at this point, the tough theoretical issues, regarding level of specificity and such, have been worked out, and it's mostly a question of doing the grunt work."

No teacher will be surprised by that: Good teaching, however it's described and whatever insights new research offers, remains hard work.

Further reading: Schoenfeld (ed.) *Cognitive Science and Mathematics Education* (Hillsdale, N.J.: Lawrence Erlbaum Associates, 1987) especially chapters 1, 2, and 8. Schoenfeld, "Mathematics, Technology, and Higher Order Thinking" in *Technology in Education: Looking Toward 2020* (Erlbaum, 1988), and Schoenfeld "Learning to think mathematically: Problem solving, metacognition, and sense making in mathematics" in *Handbook for Research on Mathematics Teaching and Learning* (Macmillan 1992) and D. Albers and G. Alexanderson, eds. *Mathematical People: Profiles and Interviews* (Boson Birkhäuser, 1985).