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ABSTRACT

A framework is described for extending the principles of apprenticeship to teaching such subjects as reading, writing, and mathematics. Such a cognitive apprenticeship is aimed at teaching students the processes experts use to handle complex tasks. Conceptual knowledge and factual knowledge are illustrated within the contexts in which they are used. The proposed framework, comprised of content, method, sequencing, and sociology, is consistent with the goals of compensatory education. The cognitive apprenticeship model is useful for all students, but is particularly effective for disadvantaged, or at-risk, students because learning is embedded in a setting that is more like work, with an authentic connection to students' lives. Examples are given of cognitive apprenticeship programs in an urban middle school in Rochester (New York), and an urban secondary school in Harlem (New York). By giving their students long-term projects that engage them deeply and by constructing an environment embodying the principles of the described framework, these schools have begun fostering cognitive apprenticeship. The two schools' progress should be followed and their methods replicated to move education to a more rational system. One figure and a 25-item list of references are included. The paper's discussant is Herb Rosenfeld in a taining piece entitled "Reflections from a Workplace for Cognitive Apprenticeship." (SLD)

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A COGNITIVE APPRENTICESHIP FOR DISADVANTAGED STUDENTS

Allan Collins
Bolt Beranek and Newman Inc.
Northwestern University

Jan Hawkins
Bank Street College

Sharon M. Carver
University of Rochester

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A COGNITIVE APPRENTICESHIP FOR DISADVANTAGED STUDENTS

Historically there has been a great divide between education for the advantaged (e.g., Latin and geometry) and training for the disadvantaged (e.g., vocational education). As education has become universal, we have extended education for the advantaged to more and more of the population, though with limited success and in watered-down form. But it is difficult for most students to understand why they should be reading *Macbeth* and learning to multiply fractions, when there is no obvious call for such knowledge in any life they can imagine for themselves. And there is increasing resistance among students to being force-fed an education that seems irrelevant to their lives.

Our thesis in this paper is that the changing nature of work in society (e.g., Zuboff, 1988) provides a potential meeting ground where education for the advantaged and disadvantaged can come together in a curriculum in which the educational tasks reflect the future nature of work in society. Work is becoming computer-based and, at the same time, requires more and more ability to learn and think. Hence, a curriculum built around tasks that require learning and thinking in a computer-based environment will make sense to both advantaged and disadvantaged students and will educate them in ways that make sense for society at large.

Only in the last century, and only in industrialized nations, has formal schooling emerged as a widespread method of educating the young. Before schools appeared, apprenticeship was the most common means of learning. Even today, many complex and important skills, such as those required for language use and social interaction, are learned informally through apprenticeship-like methods—that is, methods not involving didactic teaching but observation, coaching, and successive approximation.

The differences between formal schooling and apprenticeship methods are many, but for our purposes, one is most important: in schools, skills and knowledge have become abstracted from their use in the world. In apprenticeship learning, on the other hand, skills are not only continually in use by skilled practitioners but are instrumental to the accomplishment of meaningful tasks. Said differently, apprenticeship embeds the learning of skills and knowledge in their social and functional context. This difference has serious implications for the design of instruction for students. Specifically, we propose the development of a new "cognitive apprenticeship" (Collins, Brown, & Newman, 1989) to teach students the thinking and problem-solving skills involved in school subjects such as reading, writing, and mathematics.

Traditional Apprenticeship

To foreshadow those methods and why they are likely to be effective, let us first consider some of the crucial features of traditional apprenticeship (Lave, 1988). First and foremost, apprenticeship focuses closely on the specific methods for carrying out tasks in a domain. Apprentices learn these methods through a combination of what Lave calls observation, coaching, and practice or what we, from the teacher's point of view, call modeling, coaching, and fading. 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 the provision of scaffolding, which is the support, in the form of reminders and help, that the apprentice requires to approximate the execution of the entire composite of skills. Once the learner has a grasp of the target skill, the master reduces (or fades) participation, providing only limited hints and feedback to the learner, who practices by successively approximating smooth execution of the whole skill.

From Traditional to Cognitive Apprenticeship

Collins, Brown, and Newman (1989) proposed an extension of apprenticeship for teaching subjects such as reading, writing, and mathematics. We call this rethinking of learning and teaching in school *cognitive apprenticeship* to emphasize two issues. First, the method is aimed primarily at teaching the processes that experts use to handle complex tasks. Where conceptual and factual knowledge are addressed, cognitive apprenticeship emphasizes their uses in solving problems and carrying out tasks. That is, in cognitive apprenticeship, conceptual and factual knowledge are exemplified and practiced in the contexts of their use. Conceptual and factual knowledge thus are learned in terms of their uses 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. It is this dual focus on expert processes and learning in context that we expect to help solve current educational problems.

Second, *cognitive apprenticeship* refers to the focus on learning through guided experience in cognitive skills and processes, rather than physical ones. Although we do not wish to draw a major theoretical distinction between the learning of physical and cognitive skills, there are differences that have practical implications for the organization of teaching and learning activities. Most importantly, traditional apprenticeship has evolved to teach domains in which the process of carrying out target skills is external, and thus readily available to both student and teacher for observation, comment, refinement, and correction, and bears a relatively transparent relationship to concrete products. The externalization of relevant processes and methods makes possible such characteristics of apprenticeship as its reliance on observation as a primary means of building a conceptual model of a complex target skill. And the relatively transparent relationship, at all stages of production, between process and product facilitates the learner's recognition and diagnosis of errors, on which the early development of self-correction skill depends.

Applying apprenticeship methods to largely cognitive skills requires the externalization of processes that are usually carried out internally. 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 have no access to the relevant cognitive processes. 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. Cognitive research has begun to delineate the cognitive processes that comprise expertise, which heretofore were inaccessible. Cognitive apprenticeship teaching methods are designed to bring these tacit processes into the open, where students can observe, enact, and practice them with help from the teacher and from other students.

In addition to the emphasis on cognitive skills, 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. Cognitive apprenticeship, as we envision it, 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. Letting the job demands select the tasks for students to practice is one of the great inefficiencies of traditional apprenticeship.

A second difference between cognitive apprenticeship and traditional apprenticeship is the emphasis in cognitive apprenticeship on generalizing knowledge so that it can be used in many different settings. Traditional apprenticeship emphasizes teaching skills in the context of their use. We propose that cognitive apprenticeship should extend practice to diverse settings so that students learn how to apply their skills in varied contexts. Moreover, the principles underlying the application of knowledge and skills in different settings should be articulated as fully as possible by the teacher, whenever they arise in different contexts.

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A Framework for Designing Learning Environments

Our introductory discussion of cognitive apprenticeship has raised 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 Figure 1 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 between 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.

Domain knowledge includes the concepts, facts, and procedures explicitly identified with a particular subject matter that 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. Examples of domain knowledge in reading are vocabulary, syntax, and phonics rules.

Heuristic strategies are generally effective techniques and approaches for accomplishing tasks that might be regarded as "tricks of the trade"; they do not 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 standard heuristic for writing is to plan to rewrite the introduction and, therefore, to spend relatively little time crafting it. In mathematics, a heuristic for solving problems is to try to find a solution for simple cases and see whether the solution generalizes.

Control strategies, as the name suggests, control the process of carrying out a task. These are sometimes referred to as "metacognitive" strategies (Palincsar & Brown, 1984; Schoenfeld, 1985). As students acquire more and more heuristics for solving

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 that of 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

FIGURE 1 DESIGN PRINCIPLES FOR COGNITIVE APPRENTICESHIP ENVIRONMENTS

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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 it. 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.

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 sample problems worked in textbooks to the principles discussed in the text (Chi, Bassok, Lewis, Reimann, & Glaser, 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 others' 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.

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 & Smith, 1982). In mathematics, Schoenfeld (see Collins et al., 1989) models the process of solving problems by having students bring difficult new problems for him to solve in class.

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 direct students' attention to a previously unnoticed aspect of the task or simply remind them 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 students attempt to accomplish the target 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.

Scaffolding refers to the supports the teacher provides to help students carry out the task. These supports can take either the form of suggestions or help, as in Palincsar and Brown's (1984) reciprocal teaching, or 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, & Fisher, 1984). When a teacher provides scaffolding, the teacher executes parts of the task that the student cannot yet manage. Fading involves the gradual removal of supports until students are on their own.

Articulation includes any method of getting students to articulate their knowledge, reasoning, or problem-solving processes in a domain. We have identified several different methods of articulation. First, inquiry teaching (Collins & 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. (1984). Third, they might have students assume the critic or monitor role in cooperative activities and thereby lead students to formulate and articulate their ideas to other students.

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 depend 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 & Brown, 1988). For reading or writing, one method to encourage reflection might consist of recording students as they

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think out loud and then replaying the tape for comparison with the thinking of experts and other students.

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 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 on 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 data base on teenagers detailing their backgrounds and how they spend their time and money.

Sequencing

Designers need to support both the integration and generalization of knowledge and complex skills. We have identified some principles that should guide the sequencing of learning activities to facilitate the development of robust problem-solving skills.

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 (Van Lehn & Brown, 1980; Burton et al., 1984; White, 1984). 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 the complex set of activities needed to accomplish any interesting task. In reading, for example, increasing task complexity might consist of progressing from relatively short texts using straightforward syntax and concrete description to texts in which complexly interrelated ideas and the use of abstractions make interpretation difficult.

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 reading, task diversity might be attained by intermixing reading for pleasure, reading for memory (studying), and reading to find out some particular information in the context of some other task.

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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).

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 by both masters and other apprentices, all engaged in the target skills at various 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.

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. Where tasks have become computer-based in the world, it is important to make them computer-based in school. 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.

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 dependence. 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 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.

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).

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.

Figure 1 summarizes the characteristics of each of the four dimensions included in our framework for designing learning environments. The content and sequencing dimensions provide a striking contrast to the focus on isolated mastery of discrete lower-level skills that is characteristic of compensatory education programs developed in response to Chapter 1 legislation (Means & Knapp, this volume). On the other hand, our framework is entirely consistent with the goals of compensatory education, particularly with respect to the high level of teacher-student interaction that both the methods and sociology dimensions advocate. Though the cognitive apprenticeship environment is important for all students, we want to argue that it is particularly effective for students who are considered disadvantaged or "at risk" because learning is embedded in a setting that is more like work, where the tasks have some "authentic" relationship to students' lives and where there is a community of people working together to accomplish real-world goals (Brown, Collins, & Duguid, 1989). We contend that disadvantaged students who learn in an apprenticeship environment will not only learn the basic reading, writing, and mathematics skills that they have had difficulty learning either in regular classrooms or in Chapter 1 programs, but also develop the more advanced skills characteristic of expertise. The remainder of this paper is devoted to introducing two apprenticeship learning environments that are currently being designed and evaluated.

Two Examples of Cognitive Apprenticeship for Disadvantaged Students

We have been working at two schools during the last year where the majority of the students might be considered at risk. We will briefly describe how different forms of a cognitive apprenticeship have been implemented at the Charlotte Middle School in Rochester, New York, and the Central Park East Secondary School in Harlem to demonstrate alternative approaches to applying the principles of context, method, sequencing, and sociology outlined above.

Discover Rochester

Charlotte Middle School is an urban school located in a socioeconomically disadvantaged neighborhood. It has approximately 64% minority students and provides free or reduced-cost lunches for 56% of its students. Close to 30% of the students have been identified as moderate to high in terms of being "at risk," which means that they can be characterized by two or more of the following criteria: multiple suspensions, excessive absences, repetition of a grade, failure of two or more classes in one year, and California Achievement Test scores three or more years behind grade level.

A team consisting of two University of Rochester researchers and the eighth-grade math, science, history, English, and writing teachers conceptualized and implemented the Discover Rochester project. Generally speaking, the researchers provided theoretical background and computer training for the teachers, and the teachers contributed their expertise in curriculum design. All team members served as leaders and facilitators during actual classroom sessions, and all contributed to both formal and informal program evaluation and assessment of student progress.

The goal of this project is to raise the skill levels of urban middle school students beyond basic skills to develop sophisticated skills that will help them succeed at work and in everyday life (Resnick, 1987). It provides a model for redesigning middle school learning environments based on many of the principles advocated above, yet cast within the current constraints of an urban school system. The aim is to increase student motivation, effort, and learning by providing a learning environment that is sensitive to individual needs, interests, and abilities. To accomplish this, students are provided with computer tools that aid them in learning general thinking and problem-solving skills as they explore their community and experience ways of applying their school learning in the real world.

In a pilot of the Discover Rochester project at the Charlotte Middle School, "at-risk" eighth-graders spent one day each week exploring aspects of the Rochester environment from scientific, mathematical, historical, cultural, and literary perspectives. They worked in groups to conduct their own research about topics ranging from weather to industry to theater to employment, using a variety of strategies including library and archival research, telephone and face-to-face interviews, field observation, and

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experimentation. On the basis of their research, students developed a HyperCard exhibit for the Rochester Museum and Science Center, including text, audio, graphics, maps, and music.

The primary focus of the Discover Rochester curriculum is on explicitly teaching general strategies while students investigate multiple aspects of their own community in order to design an interactive learning exhibit. Thus, students' learning is situated in an exploration of real-world topics for a real-world purpose. The particular skills targeted by the Discover Rochester curriculum are both control and heuristic strategies for learning and communicating information. Students learned to coordinate five types of skills to complete their exhibit: question posing, data gathering, data interpretation and representation, presentation, and evaluation—an elaborated version of the Bransford, Sherwood, Vye, and Rieser (1986) IDEAL program.

In the context of the interdisciplinary work, students practiced a variety of heuristics for accomplishing each subtask. Specifically, explicit instruction was provided in the following heuristic strategies for research and communication:

- *Question posing:* (a) brainstorming techniques for generating interesting topics and deciding what students want to discover about those topics, and (b) typical sequences of questions beyond the traditional "who? what? why? where? when? how?" (e.g., when asking about someone's job, generally ask for the job title, responsibilities and risks, necessary training, etc.).
- *Data gathering:* (a) reading and listening comprehension skills; (b) strategies for using indices, headings, tables of contents, etc., for finding information in texts; (c) interviewing techniques; (d) strategies for using other nontraditional data sources, such as photographs and museum exhibits; and (e) various techniques for recording and storing information (e.g., notes, tapes, photos, and photocopies).
- *Data interpretation and representation:* (a) strategies for viewing data in historical and social contexts; (b) strategies for organizing and analyzing data (e.g., categorization); and (c) various techniques for representing information (e.g., expository vs. narrative writing, paragraphs vs. lists vs. tables, and visual representations such as maps, timelines, and graphs).
- *Presentation:* (a) strategies for considering the interests and abilities of the audience; (b) strategies for clear organization, consistency, readability, etc.; (c) specific skills for designing computer presentations, such as designing modules, and creating options for interactivity; and (d) skills for verbally describing a nonverbal presentation.
- *Evaluation:* (a) strategies for self-evaluation as well as peer evaluation, (b) techniques for surveying users to get their feedback about a presentation, and (c) strategies for considering and incorporating suggestions.

In terms of sequence, instruction progressed from global to local focus and from less to more complex tasks by starting with an overview of all five skill areas, highlighting heuristics already possessed by students or easily within reach. For example, when asked about alternative representations for information, students readily suggest paragraphs, lists, and drawings. The lesson then would begin with showing how the same information can be presented in all three forms and proceed to discussion of which forms would be best in which situations. As students began to understand the overall goals, teachers introduced the more advanced heuristics. For example, once students started to generate and evaluate alternative representations using text and pictures, teachers introduced new types, such as timelines, graphs, and maps. Diversity increased as students worked on more and more aspects of the exhibit. For example, teachers and students began to discuss diverse types of graphs, such as line, bar, pie, etc.) as a wider variety of graphing situations arose. Also, the interdisciplinary aspect of the project incorporates domain knowledge from four subject areas to highlight the use of similar general strategies in all of them. For example, history concepts of city growth and science concepts of animal and plant distribution might both be represented using maps.

The teaching methods used in the Discover Rochester project exemplify all six of the principles described under "Method" above. The lesson sequences began with explicit descriptions of heuristics for each type of skill and teacher modeling to demonstrate alternative approaches. Next, students practiced on prepared materials designed to provide scaffolding in some of the five skill areas to allow students to focus their attention on particular areas. Finally, students spent most of their time in individual or small-group practice in the context of self-directed exploration. As students worked on their projects, teachers provided additional coaching and scaffolding as needed. Students also spent a significant amount of time articulating their understanding and reflecting on their progress as they designed and evaluated their exhibit.

The Discover Rochester learning environment was designed to embody a community of practice by resembling the natural work environment. Students worked primarily in one room for a two-period block of time in the morning and another in the afternoon, rather than switching rooms every 40 minutes. Students had ready access to computer tools for facilitating their work (8 Macintosh computers for 20 students). They learned to use MacPaint, MacWrite, CricketGraph, and HyperCard to the extent that they found the software tools useful. Students also took an active role in directing their own learning. By selecting their own topics within Discover Rochester and choosing when to work independently and collaboratively, they could focus on their own interests, which increased their motivation for learning.

For example, at the beginning of the project, students and teachers worked as a group to brainstorm about possible topics for study. They used maps, phone books, information from the Chamber of Commerce, and other sources to help generate ideas. Students formed groups based on mutual interest. One group decided to study Rochester's environment. They chose weather as one subtopic and generated questions about the recent year's precipitation, temperature, and wind patterns, how those patterns compare with the 30-year norms, how proximity to Lake Ontario affects

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the weather, etc. With these questions in mind, they assigned each group member to research one subtopic and even planned strategies for finding information (e.g., interview a meteorologist, gather weather reports from local papers, check the library for information on climate normals, etc.). Data gathering proceeded somewhat independently, but interpretation, presentation, and evaluation were done more collaboratively to encourage consistency in the final product. Throughout the process, students called on teacher or peer assistance when they needed it. In addition, explicit lessons in general techniques were interspersed with the ongoing activity of the group (e.g., effective interviewing techniques), and teachers sought opportunities to practice subject area skills (e.g., interpreting graphs).

During the pilot project, we observed impressive improvement in the students' intrinsic motivation. Initially, students were sluggish, uncooperative, and unimaginative. Some refused to talk at all. The initial brainstorming session was more a lesson for the teachers in pulling teeth. As the students developed new skills (particularly computer skills), they began to participate more often, and many students took initiative beyond expectations. One student took two pages of notes from library work done during a free period. Another contacted administrators and legal counsel about the possibility of conducting a survey in the school. A third learned how to do animation in HyperCard. A fourth student made posters for the community showcase day, and about a third of the group started working voluntarily during their lunch periods. The students not only developed the five aspects of research and communication skills but also generated creative strategies for gathering and presenting information.

As the students became more engrossed in the project, behavior problems became almost nonexistent. During the first few days, there was a lot of off-task behavior in both large- and small-group work, and students were more interested in what happened in the hall between periods than in what happened in the classroom. Over time, students started ignoring the activity in the hall between periods as they pored over their work. Other teachers could not believe that we would take these "troublemakers" on field trips, but the students were polite and cooperative on all three trips we took.

On the first day of the project, students in the hall questioned why the "dummies" got to use the new computers and they did not. The participating students initially perceived themselves according to the labels of their peers. As they became proficient with the computers, they received a lot of positive attention from both peers and teachers who were curious, envious, and in awe of what the "dummies" had accomplished. The participants began to perceive themselves as more competent than they had before, both in terms of their current skills and in terms of their future career plans. One girl, who won the award for the hardest-working student, commented in a television interview that she believed that she could do more things than she had before. Another has decided to pursue a career that involves computers.

As the students explained their work to others, it was obvious that they felt a sense of pride in how much they had learned. At the same time, their standards for "good work" became stricter. Initially, students approached their work by looking for the quickest and easiest solutions. Before the students' first version of the HyperCard exhibit went into the museum, they talked about how good it was and were convinced that there was nothing they wanted to change. After interviewing students from other schools who actually used the exhibit and found it boring, they started reflecting on ways to improve their work. They actually implemented many of their ideas and started paying more attention to detail and to audience as they added to the project; but, more significantly, as they explained their work to peers and adults on the showcase day, they discussed what they would like to improve in addition to bragging about what they had done.

Many of the students involved in the project qualified for Chapter 1 instruction. Some had been placed in pull-out programs for reading and others received in-class help from the writing resource teacher. Despite the fact that these students missed their special instruction to participate in the project, their teachers reported that they improved more over the course of the project than similar students who had received the regular Chapter 1 instruction.

Though the students and teachers who participated in the Discover Rochester pilot project spent only one semester working together, they began to develop new skills, pride in their work, and a sense of community. By sharing experiences, helping each other conquer difficult problems, and working toward a common goal, they began to show signs of the investment and mutual dependence that helps shift distraction to focus, resistance to initiative, and a critical attitude to a constructive one.

These informal evaluations of student progress are positive, but more formal evaluation of the project is necessary to determine whether the program is achieving each of its specific goals, why it is working or not working, and how the effective parts of the project can be exported to other sites and other grade levels. Such formal evaluations will be initiated during the 1990-91 school year. In the meantime, however, similarly positive results are emerging from other projects incorporating aspects of the framework we have provided. For example, Roy Pea (Institute for Research on Learning) and Richard Lehrer (University of Wisconsin, Madison) have implemented programs in middle school science, social studies, and problem-solving classes. Also, the Genesee River Valley Project is an example of an interdisciplinary curriculum, like Discover Rochester, that has been developed for third- to sixth-grade urban students. For large-scale implementations such as these, the formal evaluation must unfortunately be postponed until a stable implementation is achieved, which is often a multi-year process. The Central Park East program is such a case.

Central Park East Secondary School

For the past 12 years, Central Park East Elementary and Secondary Schools have been creating and refining a learning environment that successfully challenges prevailing assumptions about the problems that urban minority students have in achieving higher-order learning goals. The secondary school has 300 to 400 students and serves a primarily minority population (about 90%), many of whom are eligible for the free-lunch program (about 60%). The school's curriculum affirms the central importance of students' learning how to learn, how to reason, and how to investigate complex issues that require collaboration, personal responsibility, and a tolerance for uncertainty.

The secondary school (CPESS) receives slightly over half its students from three elementary schools based on the Central Park East (CPE) model. In general, students are selected for the schools on a first-come, first-serve basis, but preferences are given to siblings and, in the secondary school, to students who are likely to adapt to the culture of the school. Of the first class that entered CPESS five and a half years ago, approximately 75% are still in the school, 15% changed schools after the eighth grade, and 10% left because they moved or by mutual agreement. In later classes, fewer have left the school, and school officials know of only one actual school dropout. Attendance at the school averages over 90%, and there are very few suspensions or fights. The students do better than city or state averages on the Regency Competency Exams. In summary, the school is remarkably successful in educating its students by almost any measure.

In every class, students learn to ask and answer these kinds of reflective questions:

(1) From what viewpoint are we seeing, reading, or hearing this?

(2) How do we know what we know? What's the evidence, and how reliable is it?

(3) How are things, events, or people connected? What is the cause and effect? How do they fit?

(4) What if. . .? Could things be otherwise? What are or were the alternatives?

(5) So what? Why does it matter? What does it all mean? Who cares?

A core of curriculum is offered to all students, organized around two major fields: mathematics/science for two hours and humanities (art, history, social studies, literature) for two hours. Every effort is made to integrate academic disciplines, so that students recognize and understand the relationships among different subjects of study. The communication skills of writing and public speaking are taught in all subjects by all staff. The organization and scheduling of the curriculum allow for maximum flexibility. Each team of teachers offers a variety of styles of teaching, including group presentations, smaller seminars, one-on-one coaching, and independent work in the studios, science labs, and library.

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At CPESS, the school year is divided into trimesters, and student work in each interdisciplinary curriculum area (math/science and humanities) is organized around comprehensive student projects, called exhibitions. The team of teachers in two grades of math/science, for example, collaboratively generates the curriculum for the trimester and specifies the requirements for the exhibition. Staff development at the school consists almost entirely of teachers meeting together in small groups for half a day each week to plan curriculum, as do the math/science teachers. By the end of the trimester, each student has completed a product that fulfills the requirements for the exhibition. In addition, each has done an oral presentation for a teacher in which he or she explains the exhibition and demonstrates understanding of the fundamental ideas.

The exhibitions the teachers assigned were based on real problems of the world. For example, in the first trimester of the math/science classrooms where we have been working, 9th- and 10th-grade students designed amusement park rides and specified—through multiple representations—the physical motion principles exhibited by their designs. In the second trimester, they focused on the physics concepts for a projectile motion of their own choosing (e.g., a foul shot in basketball, a curve ball in baseball). In the third trimester, the students worked on exhibitions involving two-body collisions. In the latter two trimesters, their work involved using a sophisticated simulation system for the Macintosh called Physics Explorer (there were four Macintoshes in two of the four 9th/10th grade math/science classrooms). They created models reflecting the kinds of motion they were studying and developed graphs plotting vector components against time. Much of their written work involved explaining changes in the vector components. Every student in the 9th and 10th grades at CPESS is working on serious physics problems, whereas, at most, 10% of students in the rest of the country study physics.

Three aspects of the way the school is organized reflect a cognitive apprenticeship approach to education. First, learning is situated by having students engage in projects that relate to the world about them and help them to make sense of that world. Because of their long-term nature, the projects reflect much more closely the nature of work. Students become invested in them over time and gain an ownership of the ideas they develop. For example, in the projectile motion project, one student calculated the speed and angle necessary for a stunt car driver he admired to jump over the Grand Canyon (which is not possible). When they work on projects, students use a variety of resources: the library, computers, and, importantly, the adults and other students around them, just as people do when they work. The teacher assumes the role of coach to help the students attack the problems that arise as they work on their projects, and so the student has a kind of autonomy not present in most schooling.

The second aspect of the school that we think critical is the emphasis on articulation, reflection, and exploration in learning. In presenting their exhibitions, students are required to make coherent presentations of their materials and to answer difficult questions on the fly that probe their understanding of what they have done. The effect of this training showed up in one 10th-grade girl, who on our first visit to the school was asked by her teacher to explain to us what she had done on a difficult math problem that she knew she had worked incorrectly (the problem: find the area above a right triangle inscribed in a circle, given an angle of 30° and the length of the hypotenuse). As she articulately explained her work, our questions about why she had done each step helped her find the two errors she had made. The emphasis on reflection is embedded in the kinds of questions students are taught to ask, and in the ways that they are forced to think about what they have done in order to explain and justify their work. The emphasis on exploration derives from the project-based nature of much of their work and the autonomy this fosters in students to control their own learning.

The third aspect we think is critical to the school's success is the learning culture that has arisen among the students and staff of the school. Developing this culture depends partly on starting in one of the three elementary schools that feed students to CPESS and that share the same philosophy of caring about students. Such caring is evident in the fact that there are only about five fights in the school each year, many fewer than in the other schools serving the same population. But it is most evident in the way the students bond to teachers, particularly their advisors (1 staff to every 12 or 13 students) and in the community sense that derives from the small size of the school and the trips they take together. This community feeling in the school fosters cooperation as students try to accomplish the difficult tasks they are given.

Conclusion

By giving students long-term projects that deeply engage them and constructing an environment that embodies the principles described in our framework, these two schools have gone some way toward fostering cognitive apprenticeship. Many of the students at the two schools are the kinds of students who are labeled "at risk" in other environments. But working on difficult projects that make sense to them and challenge them leads to dramatic increases in their motivation to learn and think. Instead of treating these students as failures, the programs succeed by treating them as adult workers.

By centering education around projects, we do not rule out teaching particular disciplines. Central Park East Secondary School, for example, centers its projects in particular disciplines, such as history or physics. The projects are designed to teach the most essential knowledge in the different disciplines. But all the projects are interdisciplinary: for example, the project on projectile motion involved reading, writing, mathematics, and history, as well as physics. What we are advocating, then, is quite compatible with practice in our best schools.

Most schooling emphasizes the teaching of abstract knowledge, such as arithmetic algorithms and grammar rules, that have little grounding in what students see as useful. Schools usually attempt to teach students to apply these abstractions with word problems and other artificial tasks. Our argument (Brown et al., 1989) is that this approach is backwards. We need to engage students in authentic tasks and then show them how to generalize the knowledge they gain. Instead, educators have usually attempted to give students who do not master the abstractions more and more practice or simplified versions of the same kinds of tasks. This approach is a recipe for destroying anyone's motivation to learn or think.

By embedding education in authentic tasks, what is taught will be both useful and usable. It is useful because it reflects the kinds of activities people encounter in the world. It becomes usable because students learn to apply the knowledge in accomplishing tasks. What are authentic tasks? Our argument is that they should reflect the changing nature of work and life. They include tasks like: (a) understanding complex systems (e.g., computer systems, electronic systems), (b) finding information about different topics in a large data base, (c) writing a report or making an argument about some topic, (d) analyzing trends in data, (e) investigating a particular topic to answer some open-ended question, (f) interpreting a difficult text, and (g) learning about some new domain. Accomplishing such tasks in the future will depend on using computers and electronic networks. We should not continue to educate students to communicate and calculate and learn and think with primitive tools like card catalogues and arithmetic algorithms. It is like teaching people to drive a car by having them practice riding a bicycle.

The place to encourage change in education toward a more rational system is in education for the so-called disadvantaged students because these are the students who have not been able to acquire even the basic skills in regular classrooms and because the current compensatory programs are often "widening the gap in terms of achievement of the more advanced skills" (Means, Schlager, & Knapp, 1990). We see the beginnings of an apprenticeship approach at Charlotte and Central Park East, and we think it is worth a major investment in resources to evaluate these models carefully and try to replicate them elsewhere in our failing schools. We suggest that both the design and evaluation of subsequent apprenticeship environments be based on the four dimensions in the framework we proposed:

- *Content.* Focus instruction and assessment on general strategies for accomplishing tasks, for directing one's own behavior, and for learning new material, as well as on domain-specific concepts, facts, and procedures.
- *Method.* Use teaching methods in which students learn by observation and guided practice in the context of defining and solving problems and in which discussing and evaluating developing skills is as important as practicing them.
- *Sequence.* Sequence lessons so that students begin with a clear sense of the high-level skills they are seeking and then acquire the component skills as they work on authentic problems of increasing complexity and diversity.
- *Sociology.* Offer students an environment that reflects the changing nature of work in society by initiating realistic activities, promoting communication and

collaboration among students and teachers, and providing appropriate tools for learning.

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DISCUSSION: REFLECTIONS FROM A WORKPLACE FOR COGNITIVE APPRENTICESHIP

Herb Rosenfeld
Central Park East Secondary School

For the last 30 years I have been a teacher, curriculum developer, school administrator, and staff developer in the New York City Public School System. This career has included working at Walton High School, the Bronx High School of Science, Manhattan Center for Math and Science, and, most recently, the Central Park East Secondary School (CPESS), one of the schools described by Collins, Hawkins, and Carver in their paper on cognitive apprenticeships for disadvantaged students.

Early in my career, I became interested in the mathematics curriculum and the difficulties generated by the seemingly random selection of ideas that are studied. One startling realization was that the congruence proofs students did in their study of plane geometry did not give them an insight into the nature of a deductive system or into the significance of Euclidean geometry in the development of mathematics and science. My concern with what wasn't working in math classes ultimately led me to look more closely at problems of classroom management, teacher–student and teacher–teacher relationships, staff development, school leadership, and the basic tenets of pedagogy and school organization.

The Roots of Central Park East

In the fall of 1984 Deborah Meier asked me to join her in establishing a grade 7-12 public secondary school in East Harlem. Students would be accepted into CPESS on a first come, first-served basis. As assistant director, my responsibilities included not only the role of vice principal but also leadership in the development of the math/science program. The vision that Deborah and I developed was generated from a small number of axiomatic beliefs about the way children learn, and was greatly informed by the work of Ted Sizer. In fact, our school became a charter member of Sizer's Coalition of Essential Schools.

Classroom experience dictated to both of us that students have unique ways of making sense of the world and that teachers must be able to observe and talk to students while they are on task. The Coalition of Essential Schools reflects this same belief in its position that students must be workers and teachers must be their "coaches." To create an arrangement where this could happen without affecting our budget, we felt that we had to rethink our daily schedule so that class size could be reduced to a maximum of 20 students.

In addition to the belief that people learn best by doing, we believed that ideas are more deeply understood and appreciated when they are embedded in a context (i.e., mathematics embedded in science, literature embedded in history, etc.). Further, we agreed with Sizer's argument that high schools take on so many tasks that they rarely do any one of them very well. Accordingly, we selected two main academic focuses--math/science and humanities (a single curriculum for literature, history, and fine art). We chose to offer only a single foreign language (Spanish). Finally, our conviction that people function best in a personalized atmosphere led us to assign each member of the faculty (including Deborah and myself) the responsibility for a daily advisory with between 10 and 15 students. The result is an academic school day consisting of two 2-hour long blocks (math/science and humanities) and two 1-hour classes (Spanish and advisory). An additional hour at mid-day allows for lunch, physical education, student-teacher conferences, and access to the library and computers. This schedule made it possible to reduce maximum class size to 20. Since students work with only three different teachers each day (their advisor is almost always one of their academic teachers as well), the teachers and students develop strong personal relationships.

The Components of Cognitive Apprenticeship at CPESS

Collins et al. describe their concept of a cognitive apprenticeship in terms of the way it deals with four key aspects of pedagogy: content, sequencing, methods, and sociology. These aspects of the program at CPESS and the ways in which they embody principles of cognitive apprenticeship are described below.

Content

The development of the CPESS curriculum started with the question that Ted Sizer poses, "How can we help students to use their minds well?" Our answer is that the curriculum must concentrate on students developing habits of mind that will make it possible for them to be life-long independent learners. Thus, in designing our curriculum we put emphasis on content that will help students acquire learning strategies, heuristics, and control strategies that will serve them not only in future schooling but throughout their lives as critical, informed citizens. We call upon students to construct arguments to grapple with questions like "Can we be sure that our economy will rebound, or are we headed for a real depression?" In doing so, we force them to focus on the validity of their evidence and appreciate the complexity of the possible conclusions. They learn to be conscious of the context of a discussion (Where did it come from? Where is it going?). They learn to ask the question "What if it were otherwise?" and to be comfortable making predictions and expressing opinions.

In terms of the domain knowledge in our curriculum, an important goal for us was to integrate the ideas of two or more disciplines (history and literature, or mathematics and science). We decided to organize our ideas around a theme, such as "The Peopling of

America." Given a theme, we were able to generate the course by posing a series of questions, such as: "Were the Native Americans the first Americans?" or "Were each of the incoming groups welcomed in a similar fashion?"

As we continue to develop curriculum content, we are guided by the following questions:

- Will it make "sense" to our students and their families?
- Can it be connected to, or drawn from, students' everyday lives?
- Will students have to use their minds?
- Is there an opportunity to find unique ways of doing it?
- To what extent does it integrate the disciplines?
- Will there be opportunities for students to reflect on the way that their understanding of the world is at variance with another model?
- Does it grapple with "big ideas"?

While we are mindful of students' needs to master skills and procedures that are often unrelated to a recognizable context, we work as much as possible to present these competencies as offshoots of meaningful projects. For example, in designing a building, one might need to find the height of the neighboring structures. In that context, proportional reasoning, symmetry, and size and scale take on a real and vital meaning.

Examples from the Mathematics Curriculum

Although we did not use the term "situated learning" as we began the design of our mathematics curriculum, our concerns were certainly very much like those expressed by Collins et al. The traditional mathematics curriculum has a number of formidable obstacles to overcome if one aspires to making mathematics accessible to all students (including those who are not college bound). The first, and perhaps foremost, barrier is the sequential, cumulative build up of abstract concepts in the traditional curriculum. It is in the nature of mathematics that information is built upon already established or accepted truths. For example, if I know that the product of a positive number and a negative number is a negative number, then I can use this information to prove that the product of two negative numbers is a positive number. This "deductive proof" concept is the basis of abstract mathematical thinking, and is a very difficult idea for high school students to grasp. Consequently, a watered down, less formal version of accumulating mathematical knowledge (that is equally as puzzling) has become the conventional curriculum in most high schools. This conventional curriculum requires the student to be adept at factoring trinomials before learning to solve a quadratic equation. What's more, the student is required first to learn to complete the square in order to understand the derivation of the quadratic formula before getting practice in using it. Factoring and completing the square are skills that atrophy at a rapid rate. (How many of your educated colleagues can complete the square?). An alternative approach is to have students grapple with situations which require the use of a quadratic equation and then find the simplest way to solve it. I would be proud of a student who, faced with an event that could be better understood by solving a quadratic equation, goes to a text to find the formula and then applies it.

It was our conviction that the practice of teaching skills and concepts unconnected to practical applications was the major factor in leaving students confused and turning them away from mathematics (and often, from school itself). Hence, we were determined to make the heart of our curriculum a collection of ideas and skills linked to, and embedded in, a problem context that is meaningful to students.

There is much mathematics embedded in the questions that normally turn up in science classes, and students can use it to generate more mathematical ideas and a deeper understanding of the science concepts. For example, the study of the human body as a system fosters the need to collect, organize, and graph data, in addition to measuring the many rates of change that keep the system going. We challenge students with questions such as: How could I calculate the average diameter of my body cells? What is the distance between my ears? How could one actually make these measurements accurately? A student will know how to measure the length of his or her index finger, but will have trouble with measures of body parts that cannot be done directly. Simple counting and measurement are familiar concepts to most students. The mathematical investigation of the more complex questions about the human body extends and uses that familiarity, while giving rise to even more complex questions and a deeper understanding of the ideas behind the questions.

Another curriculum theme used at CPESS—the exploration of motion, energy, and astronomy—strongly requires that one can uniquely determine the position (location) of an object at any given time. This involves graphing and mapping skills in addition to the measurement of rates, distances, and size. Some of the same skills used to analyze data and make predictions in studying the human body are also part of this work. Moreover, throughout science, the same geometric shapes show up repeatedly in contexts ranging from the path of a heavenly body to the shape of the human skull. The mathematical and the scientific ideas reinforce each other and eventually become one.

In the grades 9/10 math/science class studying motion, students were asked to design an amusement park ride as an exhibition. This project lasted for an entire trimester and included a scientific analysis and model (or computer simulation). These tasks led to the study of equations, trigonometric functions, and plane vectors. Much of our time was spent on the graphs of functions and "what they tell us." We decided to supplement this work with some of the ideas of geometry that did not turn up in designing amusement park rides (e.g., parallelograms, mathematical transformations, and matrices) and with the study of probability. In addition, we spent time considering purely scientific questions (that did not include location or counting) such as "How much of the moon do we get to see?"

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Sequencing

Our curriculum content starts with a "big idea," for example, motion. We then imm iately present the students with a motivating global situation (e.g., design an amusement park ride). Students invariably create a design that is too complicated for them to analyze. So, we are then propelled to the simplest motion that we can imagine, free fall. Then we might move on to projectile motion and combine the two motions, and so on. This is clearly an example of increasing complexity and diversity as described by Collins et al. It should be kept in mind, however, that although the sequence of student work moves from simple to complex problems, the entire unit is introduced with a complex question (e.g., the design of an amusement park ride) that serves as a context and motivator for working on both the simple and the more complex problems. This is typical of the way that the sequence for curriculum content at CPESS develops.

Methods

CPESS students learn and demonstrate their mastery by doing short- and long-term projects. Projects consist of research papers, oral presentations (defenses), physical models, and/or computer simulations. Any or all of this work may be supported by technology. These projects often speak to open-ended situations that allow for much speculation and can be thought of in several different ways.

The classroom is run like a workplace. Everyone has a job to do. Students work in groups and the teacher acts as a mentor/coach to each of the groups and to each student in the group. In the course of this activity teachers model heuristics and control processes for problem solving, critical mathematical and scientific thinking, and formulating questions (inquiry).

The kind of project work assigned to students at CPESS is designed to foster exploration and reflection. During a typical two-hour class, students confer with their cohort groups, search out references in the school library (the classroom library couldn't possibly contain all the research materials necessary to support all of the activity going on in the class), speak with the teacher about their projects, find materials and advice for their models in the art studio, use the computer for simulations and word processing, and reflect on their progress thus far and their design for the project. Their activities mirror those of researchers and designers in the real world. In this way, we believe they experience a real cognitive apprenticeship.

As students work on their projects, teachers provide coaching to help them see additional aspects of a problem, connect their current work to things they already know, execute a procedure more skillfully, and so on. Skillful implementation of the technique Collins et al. call scaffolding is a major issue for our teachers. There is a tendency for teachers to "give away the game" and deprive students of the opportunity to struggle through a creative moment. On the other hand, it is often difficult to get students started on the kind of "thinking" problems used in our curriculum without an intellectual push. Finding the right balance--and selecting appropriate amounts and kinds of scaffolding--is a tough problem, mostly because teachers need more experience working with students in this way.

Articulation is a major goal in our school. The exhibitions give students an ample opportunity to work on writing, oral presentation, and model/simulation making. Exhibitions often give rise to the use of technology as a medium of articulation. During the presentations, students have an opportunity to critique each other and some teachers have them make formal evaluations of presentations. Often alternative approaches are considered in these sessions.

Part of what makes the methods used at CPESS unusual is the way in which student work is evaluated. For each project, the teacher prepares a narrative report, designed so that it can be understood by the student and his family. This report assesses the students strengths and weaknesses and suggests a plan for working towards growth. Students' work is evaluated in terms of the following categories:

- Organization of the Work as a Whole
  - Does it make its point?
  - Is it easily understood?
  - Does it hang together?
- Understanding of the Math/Science Ideas
  - Does it probe ideas deeply?
  - Does it use examples and/or applications to illustrate ideas?
  - Does it make connections between ideas?
  - Does it properly cite evidence?
  - Does it explain observations?
  - Does it conjecture ?
  - Does it hypothesize and then test for validity?
- Process Skills
  - Are the data correct?
  - Are appropriate formulae correctly used?
  - Does it pay attention to details (labels, units, etc.)?
  - Are skills appropriately applied with competence?
  - Are incidental interesting facts introduced?

Sociology

Experience demonstrates that when students are interested in their work, learning flows naturally. They also function best in an environment of mutual respect. So, for starters, the curriculum must be demystified, a process that creates the kind of situated learning described by Collins et al. Consider the following typical classroom conversation:

ERIC

"Where are we going in this year's work?"

"We are going to study motion."

"Why?"

"Well, all things are in motion."

"You mean, I am in motion. . . ."

This is a dialogue of mutual respect with more complex questions developing as we up the intellectual ante. The teacher (coach) carries on this dialogue with groups of three or four students, the entire class, or individual students (e.g., when a student presents her project). Students carry on the same kind of dialogue within their cohort teams and as they present their work to each other. CPESS is a task-driven environment in which students work in groups and develop both group products and singular ones. This environment allows for knowledge sharing, strategy building, and the analysis of each other's work. It seeks to develop intrinsic motivation by stimulating students to pose and investigate questions that are interesting and meaningful to them.

It is an atmosphere that encourages intellectual challenge, that poses open-ended questions like "What if gravity was a horizontal force?" and requires rigorous defense of arguments made in the ensuing discussion. Encouraging this kind of imagining in students demonstrates mutual respect and encourages the development of what Collins et al. call a community of practice as students work with teachers and with each other on authentic, serious problems.

Staff: Teaching, Learning, and Leadership

The cognitive apprenticeship, as described by Collins et al. and embodied in the program at CPESS, requires teachers to play a very different role from that of dispenser of knowledge (the role seen in most conventional classrooms). Teachers need support in assuming this role, and our experiences at CPESS may be helpful to other schools considering such innovations.

The integrated, two-hour long classes are led by a teacher in one of the disciplines (e.g., either a math or a science teacher), but each teacher works toward becoming a generalist (i.e., a math/science teacher) who is equally able in both areas.

Teachers have a great deal of responsibility and decision-making power in our school. The teachers in a particular curriculum thread work in teams (in the same mode as the students who are working in groups) to build a course of study, research and create learning materials, schedule trips, bring in outside resources, create modes of student assessment, and generally support each other. A significant aspect of this collaborative effort is the sharing of each other's specialities (most high school teachers have taught courses outside of their area of specialty but have had to learn the course content on their own). This sharing often leads to brainstorming about classroom management, ways of constructively relating to particular students, and strategies for solving pedagogical problems in general. The process is, in fact, a built-in peer staff development structure. The team members are scheduled so that their in-school planning hours coincide. They have a single block of three hours for planning one morning each week as well as lunch hours (which they often spend together).

Because curriculum teams need leadership, a team leader is designated for each curriculum. The leader coordinates the team's activities, sets deadlines, looks ahead to what is down the road, finds new teaching materials, brings in outside experts, keeps up with national and local research on classroom practices, confers regularly with both the administration and with other team leaders, arranges for team representation at significant events in and out of the school, helps out in classes, holds the team to its mission, and generally becomes an expert on our way of working with students. In short, the leader's role is to be the foremost advocate of the collaborative effort.

In our community of learners, the teachers as well as the students are growing. The team leader does not evaluate the team members (the team does that): rather, she works with them to facilitate a better understanding of their roles as teachers and helps them to use their strengths to perform these roles optimally. In this way, staff development is built into our collaborative team design.

In addition to the teacher team activities described above, our ongoing development as a school requires regular full staff meetings and retreats to grapple with, and reflect on, schoolwide issues. These issues include governance, curriculum sharing, world events and our school, staff relations, national trends in our work, the school's mission, and an ever-growing common vision.

How Well Do These Concepts Work at CPESS?

I believe that CPESS provides a wonderful growing experience for students. The evidence is manifest in the way the students behave in school. They are nonviolent and respectful to each other as well as to staff members. They are intellectual risk takers: they will tackle complex questions. They study math and science throughout their secondary school career. They are almost all going on to further education after graduation. Their families enthusiastically work with the staff on educational issues concerning their children. The staff works hard on all of the issues surrounding our students' education, and the school as a whole profits from the staff's mandate to make curriculum and governance decisions.

Everyone agrees that there is still room for much growth. There is much work to be done on stoking student curiosity to further increase intrinsic motivation. We are still working out a concept of homework that makes sense for students in our kind of program. We are seeking better ways to obtain diagnostic information from student behavior in class by taking anecdotal notes that will help us identify the way that each student takes in and processes ideas and what he or she really understands about the concepts we are studying. There is much more thinking to be done about the entire student assessment issue. We continue to search for connections among disciplines--to look for math content within science and literature and art within history. In other words, we are still seeking to integrate ideas better, and are considering exploring different combinations of subjects (e.g., math with art or math with social studies). We are also still working on issues concerning the use of software and the further infusion of technology into our curriculum. But this search for continued improvement in no way detracts from the value of what has been achieved already. After all, the capacity for reflection and the disposition to strive toward continued improvement in one's design are two of the basic goals of the cognitive apprenticeship.

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