1 HOW CAN WE TEACH FOR MEANINGFUL LEARNING?

Brigid Barron and Linda Darling-Hammond

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THE NEED FOR INQUIRY-BASED LEARNING TO SUPPORT TWENTY-FIRST-CENTURY SKILLS

Enthusiasm for approaches to instruction that connect knowledge to the contexts in which it will be applied has been on the upswing since the 1980s. Recommendations from an array of organizations have emphasized the need to support twenty-first-century skills through learning that supports inquiry, application, production, and problem solving. More than a decade ago, the SCANS Report (Secretary's Commission on Achieving Necessary Skills, 1991) suggested that for today's students to be prepared for tomorrow's workplace they need learning environments that allow them to explore real-life situations and consequential problems. These arguments have been echoed in scholarly research (for example, Levy & Murnane, 2004), national commission reports (such as NCTM, 1989; MLSC et al., 1996), and policy proposals (see NCREL EnGauge, 2003; Partnership for 21st Century Skills, 2002), urging instructional reforms to help students gain vital media literacies, critical thinking skills, systems thinking, and interpersonal and self-directional skills that allow them to manage projects and competently find resources and use tools.

For these capacities to be nurtured, the reports argue, students must be given opportunities to develop them in the context of complex, meaningful projects that require sustained engagement, collaboration, research, management of resources, and development of an ambitious performance or product. The rationale for these recommendations has come in part from research demonstrating that students do not routinely develop the ability to analyze, think critically, write and speak effectively, or solve complex problems from working on constrained tasks that emphasize memorization and elicit responses that merely demonstrate recall or application of simple algorithms (Bransford, Brown, & Cocking, 1999; Bransford & Donovan, 2005). In addition, there is a growing body of research indicating that students learn more deeply and perform better on complex tasks if they have the opportunity to engage in more "authentic" learning.

> **Students do not routinely develop the ability to analyze, think critically, write and speak effectively, or solve complex problems from working on constrained tasks that emphasize memorization and elicit responses that merely demonstrate recall or application of simple algorithms.**

A set of studies have found positive effects on student learning of instruction, curriculum, and assessment practices that require students to construct and organize knowledge, consider alternatives, apply disciplinary processes to content central to the discipline (such as use of scientific inquiry, historical research, literary analysis, or the writing process), and communicate effectively to audiences beyond the classroom and school (Newmann, 1996). For example, a study of more than twenty-one hundred students in twenty-three restructured schools found significantly higher achievement on intellectually challenging performance tasks for students who experienced this kind of "authentic pedagogy" (Newmann, Marks, & Gamoran, 1995). The use of these practices predicted student performance more strongly than any other variable, including student background factors and prior achievement.

This is promising, but the checkered history of efforts to implement "learning by doing" makes clear the need for greater knowledge about how to successfully manage problem- and project-based approaches in the classroom (Barron et al., 1998). The kind of teaching suggested by these descriptions is not straightforward and requires knowledge of the characteristics of successful strategies and highly skilled teachers to implement them. In this chapter, we focus on the design and implementation of inquiry-based curriculum that engages children in extended constructive work, often in collaborative groups, and subsequently demands a good deal of self-regulated inquiry.

INQUIRY-BASED LEARNING

The family of approaches that can be described as *inquiry-based* includes project-based learning, design-based learning, and problem-based learning.

The research we review spans the K–12 years, college, and graduate education and can be found across core disciplines and in interdisciplinary programs of study[1]. Two major conclusions emerge:

Small group inquiry approaches can be extremely powerful for learning. To be effective, they need to be guided by thoughtful curriculum with clearly defined learning goals, well-designed scaffolds, ongoing assessment, and rich informational resources. Opportunities for professional development that include a focus on assessing student work increase the likelihood that teachers will develop expertise in implementing these approaches.

[1] *The research literature on these approaches includes detailed cases studies, pre- and post-single sample designs, and experimental or quasi-experimental designs.*

Assessment design is critical. Designing good assessment is an important issue for *revealing* the benefits of inquiry approaches as well as for *promoting* the success of learning. Specifically, if one looks only at traditional learning outcomes, such as memorization of information or responses to multiple-choice questions, inquiry-based and traditional methods of instruction appear to yield similar results. Benefits for inquiry learning emerge when the assessments require application of knowledge and measure quality of reasoning. Consequently, we also take up a discussion of *performance assessment* and its role in both supporting and evaluating meaningful learning.

Our discussion within this chapter is organized into four sections.

First, we provide a historical perspective on inquiry-based learning in the context of the ongoing calls to develop inquiry and collaborative capacities in learners.

Next, we summarize research on collaborative small group learning. Our review focuses primarily on studies that offer data on the outcomes of cooperative or collaborative learning approaches. However, we also look at the kinds of interaction between children that lead to deeper learning and better group problem solving, and what we have learned about how teachers can support productive interactions.

In the third section, we summarize what we know about the forms of inquiry-based approaches (project, design, and problem-based) with respect to learning outcomes, supportive activity structures, and classroom norms.

Finally, we close with common design principles and recommendations about approaches to assessment.

AN HISTORICAL PERSPECTIVE ON INQUIRY-BASED LEARNING

Projects as a means for making schooling more useful and readily applied to the world first became popular in the early part of the twentieth century in the

United States. The term *project* represented a broad class of learning experiences. In early works one sees the label applied to activities as diverse as making a dress, watching a spider spin a web, and writing a letter. The key idea behind such projects was that learning was strengthened when "whole heartedness of purpose was present" (Kilpatrick, 1918).

Enthusiasm and belief in the efficacy of such approaches for school-aged children has waxed and waned, with project-based learning having been rejected as too unstructured during several eras of "back to the basics" backlash, or policymakers having argued that applied projects are only needed for vocational training. Critics of the progressive movement held that discovery learning approaches led to "doing for the sake of doing" rather than doing for the sake of learning. There is a growing consensus that authentic problems and projects afford unique opportunities for learning, but that authenticity in and of itself does not guarantee learning (Barron et al., 1998; Thomas, 2000).

The key is how these complex approaches are implemented. For example, in the curricular reforms of the post-Sputnik years, initiatives using inquiry-based approaches (typically called "discovery learning" or project learning) were found to produce comparable achievement on basic skills tests while contributing more to students' problem-solving abilities, curiosity, creativity, independence, and positive feelings about school (Dunkin & Biddle, 1974; Glass et al., 1977; Good & Brophy, 1986; Horwitz, 1979; McKeachie & Kulik, 1975; Peterson, 1979; Resnick, 1987; Soar, 1977). This kind of meaning-oriented teaching, once thought to be appropriate only for selected high-achieving students, proved to be more effective than rote teaching for students across a spectrum of initial achievement levels, family income, and cultural and linguistic backgrounds (Braddock & McPartland, 1993; Garcia, 1993; Knapp et al., 1995).

However, new curriculum initiatives focused on inquiry using complex instructional strategies were found more often to promote a significant increase in learning gains among students taught by the early adopters—teachers who were extensively involved in designing and piloting the curriculum and who were given strong professional development. These effects were not always sustained as curriculum reforms were "scaled up" and used by teachers who did not have the same degree of understanding or skill in implementation.

At the present time, there is still controversy over whether inquiry-oriented approaches are effective and efficient for developing the student's basic knowledge of a domain. Implementation issues continue to be a concern for both practitioners and researchers and complicate research. Examples include studies that have suggested that "direct instruction"—usually understood as traditional lecture-based approaches—is preferable to "discovery learning." The sources of confusion are shown in a study by Klahr and Nigam (2004), which taught middle school students to set up controlled experiments and then measured the students' knowledge of experimental design and their ability to set up experiments that could appropriately control for potentially confounding variables. They labeled their conditions "direct instruction" and "discovery learning." However, both conditions included features of discovery learning, including the chance for students to explore the materials and try together to set up experiments. In their discovery learning condition, the researchers simply instructed the participating sixth graders to design experiments to evaluate variables related to the speed of a ball traveling down a ramp. In the direct instruction approach, the children were taught about the importance of not confounding variables in the context of demonstration experiments. This lesson was given after they had tried to set up experiments on their own.

Although the researchers' conclusions suggested that the direct-instruction approach yielded better learning, they failed to acknowledge that this approach included both a great deal of experimentation and some direct instruction. In addition, critics of the study's conclusion point out that in a real classroom situation children would be given much more guidance and scaffolding than took place in their discovery-learning condition. Thus the study does not prove that classroom-based inquiry approaches are do not work but only that they are more successful when combined with necessary instruction. This combination of appropriately timed direct instruction with the results of inquiry has also been found in other studies to be superior to either approach alone (see, for example, Bransford, Brown, & Cocking, 1999, box on p. 46). We return to this important principle later in the chapter.

Classroom research does indicate that well-designed, carefully thought-out materials and connected classroom practices are needed to capitalize on inquiry-based approaches. Without careful planning, students may miss opportunities to connect their project work with key concepts underlying a discipline. For example, Roth (2006) found that in an engineering-based curriculum for elementary school students engineering principles were unlikely to be discovered simply by successfully engineering solutions to problems such as building bridges or towers. Similarly, Petrosino (1998) described his observation of students building rockets in a science curriculum highlighting interesting products and a high level of engagement but no growth in learning the principles of flight. However, a slight variation in the task that required students to determine the variables related to how far a rocket will travel led to a dramatic increase in students' conceptual knowledge relative to the original project.

In recent years, the research base on inquiry approaches has grown to include both comparative studies and more descriptive classroom investigations of teaching and learning processes. There is a growing consensus on the importance of a number of design principles that characterize successful inquiry-based learning environments and that can be used by teachers as they embark on developing or enacting new curriculum. We summarize the relevant research base beginning with collaborative approaches to learning and then moving to three specific approaches to designing inquiry experiences: project-based learning, design-based learning, and problem-based learning. (See Table 1 of the Appendix for a summary of design principles that have emerged from classroom research.)

COLLABORATIVE SMALL GROUP LEARNING: EVIDENCE AND BEST PRACTICES

The technique of having small groups of students work together on learning activities has its roots in part in an experiment that was aimed at supporting friendships across ethnic groups following desegregation (Aronson & Bridgeman, 1979). This effort was based on theories of interpersonal relationship formation developed in the field of social psychology (Deutsch, 1949), and it proved successful not only at developing relationships but also at improving achievement.

Cooperative small group learning is one of the most studied pedagogical interventions in the history of educational research. E. G. Cohen (1994b) defines cooperative learning as "students working together in a group small enough that everyone can participate on a collective task that has been clearly assigned" (p. 3). This definition includes what has been called cooperative learning, collaborative learning, and other forms of small group work. This context for learning has been the subject of hundreds of studies and several meta-analyses (P. A. Cohen, Kulik, & Kulik, 1982; Cook, Scruggs, Mastropieri, & Castro, 1985; Hartley, 1977; Johnson, Maruyama, Johnson, Nelson, & Skon, 1981; Rohrbeck, Ginsburg-Block, Fantuzzo, & Miller, 2003). Overall these analyses come to the same conclusion: there are significant learning benefits for students when they are asked to work together on learning activities as compared to approaches where students work on their own (Johnson & Johnson, 1981, 1989).

For example, in a comparison of four types of problems presented to individuals or cooperative teams, researchers found that teams outperformed individuals on all types and across all ages (Quin, Johnson, & Johnson, 1995). Problems varied in terms of how well defined they were (a single right answer versus open-ended projects such as writing a story) and whether they were more or less reliant on language. Individual experimental studies have shown that groups outperform individuals on learning tasks, and further that individuals who work in groups do better on later individual assessments as well (Barron, 2000b, 2003; O'Donnell & Dansereau, 1992).

There are desirable outcomes for students in other areas of their lives as well, including improvement in student self-concept, social interaction, time on task, and positive feelings toward peers (P. A. Cohen et al., 1982; Cook et al., 1985; Ginsburg-Block, Rohrbeck, & Fantuzzo, 2006; Hartley, 1977; Johnson & Johnson, 1989). Ginsburg-Block and colleagues (2006) focused on the relationship between academic and nonacademic measures. They found that both social and self-concept measures were related to academic outcomes. Larger effects were found for interventions that used same-gender grouping, interdependent group rewards, structured student roles, and individualized evaluation procedures. They also found that low-income students benefited more than high-income students, and urban students benefited more than suburban. Racial and ethnic minority students benefited even more from cooperative group work than nonminority students, a finding that has been repeated over several decades (see Slavin & Oickle, 1981). Ginsburg-Block and colleagues (2006) conclude that those dimensions of group work that support academic outcomes also yield social and self-concept benefits.

Most recently, the focus has gone beyond the practical benefits of collaboration for individual learning to recognize the importance of helping children develop the capacity to collaborate as necessary preparation for all kinds of work. For example, the Science for All Americans, Project 2061 (American Association for the Advancement of Science, 1989) suggests that a core practice of scientific inquiry is collaborative work; schools should be preparing students for this kind of work through classroom activities that require joint efforts.

> The collaborative nature of scientific and technological work should be strongly reinforced by frequent group activity in the classroom.

> Scientists and engineers work mostly in groups and less often as isolated investigators. Similarly, students should gain experiences sharing responsibility for learning with each other. In the process of coming to understandings, students in a group must frequently inform each other about procedures and meanings, argue over findings, and assess how the task is progressing. In the context of team responsibility, feedback and communication become more realistic and of a character very different from the usual individualistic textbook-homework-recitation approach [AAAS, 1989, p. 202].

Challenges of Small Group Work in Classrooms

Although there is much consensus about the desirability of developing collaboration skills, and research is clear about the general benefits of small group interaction for learning, this does not mean that helping small groups engage in high-quality discussion and sharing is easy. Research has identified at least three major challenges for cooperative learning in classrooms: (1) developing norms and structures within groups that allow individuals to work together; (2) developing tasks that support useful cooperative work; and (3) developing discipline-appropriate strategies for discussion that support rich learning of content.

A number of studies have pointed out the importance of structure for positive group outcomes. Yager, Johnson, and Johnson (1985) examined the effect of structured and unstructured oral discussions with mixed-ability second-grade cooperative learning groups. Groups were randomly assigned and stratified on the basis of sex and ability level. Each class consisted of three twelve-minute sections: teacher instruction, oral discussion, and class discussion. During the oral discussion, the unstructured group was told to work together on the material introduced by the teacher; the structured group received roles of learning leader and learning listener. The role of the leader was to give a synopsis of the day's lesson, and the listeners were to ask questions to push the leader to give a full explanation. The structured group achieved higher scores on unit tests given at day nine and day eighteen, and on the retention test given eighteen days after the end of the unit. Given that the assessments were taken individually, the researchers concluded there is group-to-individual transfer of knowledge.

Gillies (2004) also studied structured and unstructured groups in ninth-grade math classes in Australia. The students in the structured groups were trained in cooperative social skills before working in groups on the mathematics unit. The unstructured groups were told to work together but not given any further direction. All students received a teacher-created math assessment at the end of the unit and a questionnaire recording their perceptions of the group process. The students in the structured group performed better on the math assessment and exhibited more cooperative and on-task behavior than did the unstructured groups.

Calling students' attention to how their group is functioning appears to facilitate better group outcomes. In a study of group processing, Yager, Johnson, Johnson, and Snider (1995) observed positive gains in achievement for low-, middle-, and high-ability third graders who were given processing time to discuss how their group was working and what could be done to improve their efficacy. The control group also engaged in cooperative group work without the opportunity for group processing, thus illuminating how specific cooperative learning interactions produce more positive outcomes.

The nature of the task also appears to matter. For example, Nystrand, Gamoran, and Heck (1993) did a study across nine schools and fifty-four ninth-grade English classes of the effects of small groups on achievement. They noticed that, in this sample, those who stayed in small groups longer had lower achievement. It turned out that these students were in groups assigned to tasks that amounted to "collaborative seatwork," not permitting student autonomy and student production of knowledge. The lowest-rated groups on these dimensions were those assigned grammar work rather than analysis of

Teachers must maximize opportunities to concretely connect the work to key concepts

literature. These groups scored lower on the final assessment than those who were in groups that allowed them "to interact over the substance of their problem, defining tasks as well as solutions, and constructing interpretations"(p. 20). The researchers argued that adolescents need tasks allowing them to "compare ideas, develop a train of thought, air differences, or arrive at a consensus on some controversial issue" for them to deepen their knowledge and understanding (p. 22).

Once groups know how to work together, and they have a task worth working on, they still need to learn how to have content-rich discussions that are productive of serious learning. A review of nineteen studies that focused on the nature of small group discussions in science (Bennett, Lubben, Hogarth, Campbell, & Robinson, 2005) concluded that the studies consistently show that "students often struggle to formulate and express coherent arguments during small group discussions, and demonstrate a relatively low level of engagement with tasks." The authors note that five of the seven most highly rated studies make the recommendation that teachers and students need to have explicit opportunities to learn the skills associated with developing arguments and with effective small group discussion.

In a separate review of ninety-four studies, which focused on better understanding the conditions for high-quality discussion,[2] the same group of

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[2] *With respect to methods, of the ninety-four studies twenty-eight were experimental designs, and twelve of those were randomized clinical trials. The remainder were case studies that used a variety of approaches to collect data: video, audio, interviews, observations, questionnaires, or tests.*

authors (Hogarth, Bennett, Campbell, Lubben, & Robinson, 2005) concluded: "A successful stimulus for students working in small groups to enhance their understanding of evidence has two elements. One requires students to generate their individual prediction, model or hypothesis which they then debate in their small group (internally driven conflict or debate). The second element requires them to test, compare, revise or develop that jointly with further data provided (externally driven conflict or debate)."

Findings of this kind suggest that teachers should play an active role in helping groups learn to coordinate their work on productive tasks and learn how to talk about what they are perceiving in terms that reflect the modes of inquiry in the discipline.

Designing Activities for Productive Collaboration

A great deal of work has been done to specify the kinds of tasks, accountability structures, and roles that help students collaborate well. It is generally agreed that tasks requiring interdependence of team members, accountability structures at the group and individual level, and opportunities to reflect on group progress and interaction are key elements. In Johnson and Johnson's summary (1999b) of forty years of research on cooperative learning, they identify five "basic elements" of cooperation that have emerged as important across multiple models: positive interdependence, individual accountability, face-to-face promotive interaction, social skills, and group processing (pp. 70–71).

A number of activity structures have been developed to support group work. Table 3 in the Appendix of this book summarizes well-known techniques for arranging group work. They range from cooperative learning approaches where students are simply asked to help each other complete individually assigned traditional problem sets to approaches where students are expected to collectively define projects and generate a single product that reflects the continued work of the entire group. Many approaches fall in between these two extremes. Some of these approaches assign children to management (e.g., E. G. Cohen, 1994a, 1994b), conversational (King, 1990; O'Donnell, 2006), or intellectual roles in the group (Cornelius & Herrenkohl, 2004; Palincsar & Herrenkohl, 1999, 2002; White & Frederiksen, 2005).

As the table suggests, different lines of work emphasize one or another dimension of the group work process. For example, Slavin (1991) argues that "it is not enough to simply tell students to work together. They must have a reason to take one another's achievement seriously" (p. 73). He developed a model focusing on external motivators that reside outside the group, such as rewards and individual accountability established by the teacher. His meta-analysis found that group tasks with structures promoting individual accountability produce stronger learning outcomes (Slavin, 1996).

E. G. Cohen's review of research (1994b) on productive small groups focuses more on internal group interaction around the task, arguing that the means for accomplishing what rewards and accountability offer the group process may vary with the type of task and interaction. Cohen and her colleagues developed Complex Instruction, one of the best-known and well-researched approaches. Complex Instruction uses carefully designed activities that require diverse talents and interdependence among group members. Teachers are helped to pay attention to unequal participation that often results from status differences among peers and are given strategies that allow them to bolster the status of infrequent contributors (E. G. Cohen & Lotan, 1997). In addition, roles are assigned that support equal participation: recorder, reporter, materials manager, resource manager, communication facilitator, and harmonizer. A major aspect of the approach is development of "group-worthy tasks" that are both sufficiently open-ended and multifaceted in their cognitive demands that they require and benefit from the participation of every member of the group. Tasks that require a variety of skills such as research, analysis, visual representation, and writing are well suited for this approach.

There is strong evidence about the success of Complex Instruction strategies in promoting student academic achievement (Abram et al., 2001;

E. G. Cohen, 1993, 1994a, 1994b; Cohen & Lotan, 1995; Cohen et al., 1999, 2002). In recent studies, evidence of this success has been extended to the learning gains of new English language learners (Lotan & Valdes, 2006).

In other approaches, roles are linked to specific kinds of cognitive engagement. For example, Cornelius and Herrenkohl (2004) described a classroom unit on sinking and floating that engaged children in experimentation. Students presented their theories, methods, and findings to the whole class. The audience members (their peers) were given roles to ask questions about the presenter's theories and predictions, the results, or the relationships between theories and results. Roles of this sort reveal to students what elements of the scientific process—theorizing, prediction, their relationship to data collection and findings—are important to attend to and how they should be considered. Thus the structure and modes of inquiry of the discipline (Schwab, 1978; Shulman, 1987) are made visible, and the means for evaluating scientific rigor are introduced to students.

White and Frederiksen (2005) have developed both cognitive and social roles. Students take turns being in charge of managing cognitive aspects of group work such as theory, evidence, synthesis, and application. Other students manage social processes such as collaboration, equity, communication, mediation, and reflection. Roles are taught explicitly and written guides developed to help students understand them. This makes visible and learnable those processes of thinking and behavior that would often be invisible. The notion of making thinking visible through collaborative interactions between students and teachers has also been described as "cognitive apprenticeship" (Collins, Brown, & Newman, 1989). A key aspect of an apprenticeship approach is giving students opportunities to engage in parts of a task while also giving them a view of the whole task or problem.

Another example of a successful approach to role-based collaboration comes from the domain of computer science. A collaborative approach to learning to program, called PAIR programming, has been studied using a quasi-experimental approach at the undergraduate level (McDowell, Werner, Bullock, & Fernald, 2006). In this case, the practice of working in pairs actually came about from the workplace, where a collaborative approach called Extreme Programming has been developed. In Extreme Programming, partners create code together, sitting shoulder to shoulder. One partner is designated as "the driver" and creates the code and is in control of the keyboard. The other partner is looking over her shoulder, reviewing the code to identify errors in syntax and logic or design mismatches. This approach is now being tried out in middle schools (Werner, Campe, & Denner, 2005).

Not only do students who learn in pairs generate higher-quality programs but they learn as much as students who do all their work alone, are more likely to take another class in the discipline, and are more likely to pass it (McDowell et al., 2006). Students who learned in pairs enjoyed the work more and were more confident. Perhaps most important, those students who worked in pairs during the introductory course were more likely one year later to have declared a major related to computer science than students who were taught in the traditional way, working alone. The effect was particularly strong for women, who are underrepresented in the field of computer science. Although it is assumed that collaborative work enhances motivation or confidence, few studies have looked at these outcomes explicitly. This work makes an important contribution to our understanding of the affective outcomes of collaborative learning.

What Does Productive Collaboration Look Like?

Recent research has gone beyond summative assessments of the benefits of group work to try to understand why collaboration benefits learning and what differentiates more and less successful approaches to collaboration. A number of social processes have been identified that help to explain why group work supports individual learning. They include opportunities to share original insights (Bos, 1937), resolve differing perspectives through argument (Amigues, 1988; Phelps & Damon, 1989), explain one's thinking about a phenomenon (King, 1990; Webb, Troper, & Fall, 1995), provide critique (Bos, 1937), observe the strategies of others (Azmitia, 1988), and listen to explanations (Coleman, 1998; Hatano & Iganaki, 1991; Schwartz, 1995; Shirouzu, Miyake, & Masukawa, 2002; Webb, 1985).

Research on the interactions that can occur within collaborative learning situations makes the important point that it is not simply the act of asking children to work in groups that is essential but rather the *possibility* that certain kinds of learning processes can be activated (E. G. Cohen, 1994b). Research that attends explicitly to variability in group interaction has yielded information about what productive collaboration looks like, and conversely what less-than-ideal collaboration looks like. In an experimental study comparing the problem solving of groups and individuals at the sixth-grade level, Barron (2000b) found that groups outperformed individuals, and that when students were given a new analogous problem to solve, those who had first solved the problems in groups performed at a significantly higher level.

However, more detailed analyses revealed that among the sixteen trios of students there was a great deal of variability in how well the students collaborated, and the quality of collaboration—how they talked and interacted with one another—was related to their group score and later individual scores (see the box "More and Less Successful Groups"). If a collaboration is going well, (1) many students will be involved in the discussion as contributors and responders; (2) the contributions are coordinated rather than consisting of many independent unrelated conversational turns; (3) there are few instances of off-task behavior; and (4) students attend to each other and to their work in common, as indicated by eye gaze and body position. These are good markers of *mutual engagement*, an important element of collaborative work. As discussed in the next section, it is also possible to look at the quality of the content of the discussion, for example, what Engle and Conant (2002) call disciplinary engagement—that is, the extent to which the students' conversation reflects the issues and practices of a discipline's discourse.

MORE AND LESS SUCCESSFUL GROUPS

Barron (2003) analyzed group interaction through videotapes of sixth-graders working in triads to solve a complex math problem. She contrasted teams who were more and less successful in solving the problem. Children were asked to solve the problem posed to the main character in a staged, fifteen-minute video adventure called "Journey to Cedar Creek," the first episode in the series *The Adventures of Jasper* (CTGV, 1997). The problem posed to the students was to make a decision about whether Jasper had enough time to make it home in his new boat before sunset; the boat had no running lights. To make this decision, students needed to determine (1) the number of miles to be traveled on the return trip, (2) the length of time the return trip would take, and (3) the time he would arrive back to his home dock, or the number of hours available for travel before the sunset. Students were given a storyboard with eighteen stills from the movie that helped them remember relevant scenes and quantitative information.

Part of the analysis involved coding children's conversation. The quantitative analyses established that groups who differed in their level of joint success did not differ on a number of variables that might plausibly account for the observed difference. These variables included prior achievement, the number of turns, and the number of times correct proposals were brought into the group. What differed between more and less successful groups was how peers responded to ideas. More successful groups responded to correct proposals by engaging them in further discussion or accepting and documenting them. In contrast, less successful groups had a high probability of responding to ideas with silence or rejecting them without rationale. Further analyses suggested that the conversations in less successful groups were not as aligned topically as those in more successful groups. Frequently, when a peer generated a correct proposal the conversation that was occurring just previously was not closely related to the proposal. A reasonable hypothesis is that this would make it harder for peers to recognize the significance of the proposal. However, almost half the correct proposals were directly related, and most were still not accepted or taken up in the conversation.

A second part of the analysis involved describing what was happening between children as proposals were made for solving the problem. Qualitative analyses of the conversation of four triads illustrated the broader interactional contexts in which proposals were made and responded to. These portraits depicted the challenges that arose for some triads as participants attempted (or did not) to coordinate individual perspectives into a joint problem-solving space.

In the less successful cases, relational issues arose that prevented the group from capitalizing on the insights fellow members had generated: competitive interactions, differential efforts to collaborate, and self-focused problem-solving trajectories. Behaviorally these issues manifest in violation of turn-taking norms, difficulties in gaining the floor, domination of the workbook, and competing claims of competence ("I know what I'm doing!" "No, I do!"). Although constructs such as status (E. G. Cohen & Lotan, 1995) may be called on to explain these patterns, it is informative to attend to the dynamic shifts observed. It was apparent that both speakers and listeners played consequential and interdependent roles in uptake and documentation of ideas. For example, indirect or mitigated (Linde, 1988) contributions were especially problematic in the context of self-focused peers, as when a soft-spoken suggestion was made when a partner was thinking aloud to himself. On the other hand, persistence and resistance to dominating efforts were effective strategies to combat a self-focused partner, although they may have come at some cost to continued engagement or even a future desire to work together.

Groups that did well engaged the ideas of participants, had a low rate of ignoring or rejecting ideas, paid attention to attention, and echoed the ideas of one another.

(continued)

Their successful achievement of a joint problem-solving space was especially reflected in much "huddling" around the workbooks and mutual gazing.

These nonverbal synchronies suggest an intense level of joint ownership over the production and representation of the work. It was not that more successful groups were immune to problems of coordination but rather that members used strategies that resulted in a joint focus of their attention. For example, when documenting solutions, the writer might "broadcast" his or her writing orally and thus make it available for monitoring by other students in the group. In addition, some groups explicitly monitored the group's joint attention and addressed possible disruptions to it. Thus, successful coordination was accomplished through a variety of strategies that included use of external representations (sharing pictures, writing, models), conversational devices (reading aloud, discussing, questioning, or calling for attention to an idea), and physical moves (huddling, sharing materials, maintaining eye contact).

How Can Teachers Support Productive Collaboration?

The classroom teacher plays a critical role in establishing and modeling practices of productive learning conversations. Aspects of the larger classroom learning environment shape small group interactions. Observing a group's interactions can yield a substantial amount of information about the degree to which the work is productive, as well as an opportunity for formative feedback and support for aligning understandings and goals among group members. Computer-based tools can also be useful in establishing ways of working and supporting productive collaborative exchanges. One of the best and most documented examples is the Computer-Supported Intentional Learning (CSILE) project (Scardamalia, Bereiter, & Lamon, 1994), which includes a knowledge gathering and improvement tool to support inquiry and norms for knowledge building discourse. Beyond any specific tool or technique, a particularly important role for the teacher is to establish, model, and encourage norms of interaction that reflect good inquiry practices.

A paper by Engle and Conant (2002) documents how this can be done by analyzing the productive disciplinary engagement of a group of elementary school students. This group work took place in a research-based experimental classroom designed as part of A. L. Brown and Campione's Community of Learners project (1996). They studied students' collaborative work in the context of a jigsaw approach to developing knowledge about animal species and their mechanisms of reproduction and defense. The jigsaw method divides topics among students so that each class member becomes an expert in a subtopic. Experts then teach their group members what they know so that the group benefits from the distributed work. In this case, groups of four or five students wrote proposals to study a specific animal species. The groups were then assigned an animal on the basis of the quality of their group proposal. The final product of the group was a written report, done by all members of the group. Individual students became expert on a specific subtopic such as reproduction strategies or defense mechanisms and contributed chapters that focused on these subtopics. After they shared this knowledge with their group, the entire group wrote the introduction and conclusion. Engle and Conant's analysis (2002) focuses on a single group who became highly and persistently engaged in an unplanned controversy over classifying killer whales as belonging to the species of dolphin or whale (they were assigned to research the whale). The controversy resurfaced a total of eight times across the eight-week project. They sought to understand what supported the students' persistence and their disciplinary engagement.

The controversy was sparked by contradictory claims offered by various experts (in books and among the trainers they met during a field trip to Marine World) and was sustained because different claims were adopted by opposing group members. Students' passionate engagement was reflected in intensive emotional displays, persistence in having their ideas heard, additional research, and continued attention over weeks. A key aspect of their discourse that afforded productive learning conversation rather than devolving into an argumentative shouting match was the appropriation of scholarly moves such as use of various kinds of evidence to justify their claims. In addition, analysis of talk made it clear that although at times students spoke over one another and competed for floor time, they held themselves accountable to the contributions others made. This was indicated by the proportion of turns in which students associated particular group members with controversy-relevant claims, or evidence. The authors call this process "positioning."

Their analyses stress the importance of understanding the classroom environment, the curriculum, and the guidance of the teacher as a system; they highlighted four principles, described here with examples of how the teacher, Ms. Wingate, communicated them to students and realized them through activities and resources:

Problematize subject matter by encouraging students to define problems and treat claims and explanatory accounts, even those offered by "experts," as needing evidence. Ms. Wingate encouraged students to question all sources. Rather than ignoring differences across sources, Ms. Wingate drew attention to them: "One book says one thing, and other books say another thing . . . you need to figure out which one is right" (Engle & Conant, p. 431). She helped them see the importance of looking for converging sources: "Compare sources, and see if they are the same" (p. 431). She also reminded students that they had used this same strategy in a recent history unit.

Give students authority to address such problems by identifying them with claims, explanations, or designs in ways that encourage them to be authors and producers of knowledge. Ms. Wingate explicitly communicated her enthusiasm for debate and productive conflict. For example, when a student communicated to her that a research group was having a big fight about research, she said "I love that!" (p. 431). She also marked the expectation that each student would become an expert in a subtopic, which she defined as “the person who knows everything about that” (p. 432). She also emphasized that the students would become more knowledgeable than she: “And you guys are researching a lot of things that I don’t know things about. And so when you find information, I’m going to ask you questions about it, just like anyone in the classroom is, who doesn’t know things about it” (p. 432).

Hold students accountable to others—such that they are responsible for addressing others’ viewpoints even if they disagree—and to shared disciplinary norms, such that they pay attention to evidence, using practices of the discipline. Ms. Wingate encouraged the students to incorporate a range of sources into their research. She suggested they use “as many books as you can, and experts, and the computer, and write to the science desk, and do as many things as you can” to learn about their research areas (p. 433). Students were also constantly made aware of the requirement that they help their group members learn: “Let’s say, Ron, you become an expert of panther babies, and Jamal becomes an expert on panther protection. You’ll need to teach Jamal everything you know about babies, and he’ll teach you everything he knows about protection, so when you go to the jigsaw group, you’ll need to talk about the whole panther, not just the panther babies” (p. 433). A final type of accountability that was key to this group’s learning was accountability to having evidence and being able to cite sources. Ms. Wingate established early on that they would need to keep track of where they found information: “You may find some information in this movie, that’s going to be important to you at some other time. And if you ever want to say where you got your evidence, you can look back in your book, and say ‘Ah, I saw it in *Hawaii: Threatened Paradise*. . . .’ So it’s really important that we start writing down where we get our information” (pp. 434–435).

Provide students with relevant resources such as models, public forums, or tools that support discussion. Informational resources such as books, magazines, films, access to experts, and field trips were critical in allowing students to find a broad range of topics, contradictions, and perspectives. These discrepancies were important for driving debate but also for developing students' reasoning and sophistication in using numerous types of evidence. In addition, throughout this unit and other units Ms. Wingate offered models of how to build up arguments with evidence. For example, one student explained how to engage in debate based on evidence from an earlier unit on the use of DDT to fight malaria:

"So maybe I decided malaria [was worse] and Ms. A decided DDT was. Ms. A might say 'I think DDT because of this,' and then I would raise my hand because I have something to say to that. I'd either want to BACK her up and say 'yeah and also this' (gestures a point), or I'd want to say 'oh NO, I don't think that, because I think Malaria is worse, because of THESE reasons' (gestures multiple reasons)" [pp. 427].

Project-based, problem-based, and design-based learning demand strong scaffolding, assessment, and flexibility

Another important resource was time. Students were given plenty of time to investigate this question and opportunities to share the group's current thinking and disagreements with one another and with Ms. Wingate, the class, and a student teacher. Ms. Wingate repeatedly reflected back what she heard: "It sounds like there's not a group decision on this" and later, "I think you have got different sides of an argument that both sides I feel like have good points" (p. 440). She encouraged less vocal students to weigh in and consistently asked for evidence.

In Sum . . .

A great deal of research has shown that collaborative approaches to learning are beneficial for individual and collective knowledge growth, including development of disciplinary practices. Studies also indicate that such approaches can help students develop affective qualities, such as confidence and motivation. Research is also beginning to show that teachers can support expression and development of collaborative capacities through careful design of activities, assessments, and methods for establishing and maintaining classroom norms that support productive joint work. We now turn to research on specific approaches to activity design that engage students in inquiry and sustained project work.

RESEARCH ON INQUIRY LEARNING APPROACHES

The design of most inquiry-based approaches is based on insights from cognitive theories about how people learn and the importance of students both making sense of what they learn and processing content deeply so that they truly understand it (Bransford, Brown, & Cocking, 1999). There are many ways to accomplish these goals, and this has given rise to several distinct genres of approaches. In this review we summarize research on three of the more well-researched strategies: project-based learning, problem-based learning, and design-based learning, which share both similarities and differences.

Project-Based Learning

Project-based learning (PBL) involves completing complex tasks that typically result in a realistic product, event, or presentation to an audience. Thomas (2000) defines productive project-based learning as (1) central to the curriculum; (2) organized around driving questions that lead students to encounter central concepts or principles of a discipline; (3) focused on a constructive investigation that involves inquiry and knowledge building; (4) student-driven, in that students are responsible for making choices and for designing and managing their work; and (5) authentic, by posing problems that occur in the real world and that people care about.

Implementing Project-Based Learning—Districtwide

According to Robert J. Van Maren, superintendent of the Bonner Springs/Edwardsville School District, in Bonner Springs, near Kansas City, Kansas, "It's essential that learning not only be fun, but also be something that teachers and kids can get passionate about. I've never seen anyone be passionate about testing, but as a result of No Child Left Behind and other like initiatives, that's what we've been forced to offer."

To change the paradigm, Van Maren championed a recent effort to bring the project-based Expeditionary Learning Schools (ELS) Outward Bound model to his own school district—a type of learning that's been very successful at other schools around the country. In this model, the focus is on learning "expeditions": long-term student investigations that, though keyed to state and federal academic standards, are designed to nurture a strong affinity for dynamic learning and a curiosity about the world beyond the classroom. In ELS, the focus is on learning by doing, as opposed to the more passive traditional class experience.

FINDING FUNDING

As a result of Van Maren's efforts, Kansas City's Ewing Marion Kauffman Foundation awarded five-year, $150,000 grants to four of the district's schools—three elementary schools and one middle school—to support their transformation into Expeditionary Learning Schools. That brought the total number of ELS in the Kansas City area to eleven, giving the region the opportunity to become the flagship of the movement.

Van Maren believes this is where their schools are headed—and that they'll get there without compromising national and state standards in the process. "I'm an old science teacher, and I know that kids learn by doing, not by sitting there doing worksheets or practice tests," he said. "This grant allows us to use the best pedagogy available to teach using an investigative style, so kids can discover the linkages between what they're learning—not just math for math's sake, or science for science's sake. We believe that the test scores will take care of themselves."

By test scores, or almost any other method of accounting, ELS has a successful track record in education reform. After it had been in operation for just six years, Congress hailed it as a national educational model, and schools from coast to coast were signing up. In 2003, the Bill & Melinda Gates Foundation awarded ELS a five-year, $12.6-million grant to create twenty small college-preparatory high schools.

That track record was one reason the Kauffman Foundation chose to fund ELS. Another was diversity. "In Kansas City, we have a huge range of school settings—large, small, rural, urban, suburban, wealthy, not wealthy—so we looked hard to find an innovative program that could accommodate our needs," said Margo Quiriconi, the organization's director of research and policy. "Their model has been successfully implemented in almost every kind of school imaginable."

GETTING BUY-IN

The success is in part due to an ELS mandate regarding program buy-in: Before a school can apply, the school board must unanimously approve it, and 80 percent of school staff must agree on the proposal.

"Even though this is a school-based model, not a district-based model, we can't pick a school if we don't have support from the top down," said Corey Scholes, a former K-8 principal who is now the ELS representative working with the Bonner Springs schools. "Changing an entire school culture is really hard work. You just can't do it without the support of both administration and the teachers. The Bonner Springs school system showed an intense dedication to the model."

Joseph DiPinio, principal of grant recipient Robert E. Clark Middle School, was a staunch supporter from the beginning. "As part of the grant process, we visited Expeditionary Learning Schools around the country, and in every instance I walked away with the thought, 'That's how I want my school to be,'" he said. "When you see something good for kids, you want to figure out a way to make that happen, but the costs for the professional development and the school design are so extensive. We wouldn't have been able to afford to do this comprehensively on our own."

"My passion has always been professional development for teachers, and now I get the pleasure of working on site with teachers twenty-five days a year," Scholes said. "I would have sawed off my left arm to have this kind of support when I was a principal."

Though excitement about the new venture is evident, Bonner Springs's superintendent acknowledges that the next five years will be challenging.

"Change is difficult, and it's always easier to just keep doing what you've always done," Van Maren said. "But we want different results. We want our kids to reach a new level of potential and be competitive with kids all over the world. Just as important, we want to bring the joy and passion back into the classroom. We want to create a learning experience that kids and teachers will never forget."

MORE INFORMATION

- For more on the Expeditionary Learning Schools Outward Bound model, go to www.elschools.org.
- A video about the ELS program at King Middle School in Portland, Maine, can be seen at www.edutopia.org/expeditionary-learning-maine-video.
- To read about King's program, see "Expeditionary Learning (page 40)"

Adapted from Edutopia article "River Journeys and Life Without Bathing: Immersive Education," by Laura Scholes. Originally published May 15, 2007.

There are a number of research strands that contribute to our understanding of the effects of project-based learning. One has examined the strong success of whole-school models such as Expeditionary Learning, which create an entire curriculum grounded in "intellectual investigations built around significant projects and performances" (Udall & Rugen, 1996, p. xi). Expeditionary Learning schools' approach to project-based learning also focuses on teamwork, community building, and connections beyond the school. They use a pedagogy that emphasizes performance-based assessment, reflection on learning, and revision of work to meet standards in the discipline. Evaluation of schools that have implemented this model has found substantial gains in student learning as measured by standardized test scores, as well as an increase in student motivation and teachers' confidence in their ability to reach all students (ELOB, 1997, 1999a, 1999b; New American Schools Development Corporation, 1997).

Another group of schools using project-based learning as the center of the curriculum, the Co-nect schools, which add an emphasis on technology, were found to exhibit larger value-added student achievement gains on standardized tests than a group of comparison schools in Memphis, Tennessee (Ross et al., 1999) and to exhibit gains comparable to the district average in Cincinnati, Ohio (CPS, 1999). These whole-school efforts to implement project-based learning approaches include a broad range of organizational and pedagogical strategies that make it difficult to isolate the "effects" of project-based learning in a controlled, experimental fashion. At the same time, they allow us to examine PBL in an authentic context, where the principles that drive the approach—student-centeredness, authenticity, disciplinary inquiry—extend to decisions about all the other aspects of the school organization. In that sense, these examples may be viewed as a comprehensive test of the principles that guide project-based learning.

Generally, project-based learning sees students who engage in this approach benefit from gains in factual learning that are equivalent or superior to gains for those who engage in traditional forms of instruction (Thomas, 2000).

The goals of PBL are broader, however. The approach aims to enable students to transfer their learning more powerfully to new kinds of situations and problems and to use knowledge more proficiently in performance situations. There are a number of studies demonstrating such outcomes in both short- and long-term learning situations.

For example, Shepherd (1998) describes the results of a unit in which an experimental group of fourth and fifth graders completed a nine-week project to define and find solutions related to housing shortages in several countries. In comparison to the control group, this group of students demonstrated a significant increase in scores on a critical-thinking test, as well as increased confidence in their learning. Other short-term, comparative studies of traditional vs. project-based approaches have demonstrated such unique benefits for projects as an increase in problem definition (Gallagher, Stepien, & Rosenthal, 1992), growth in use of arguments to support reasons (Stepien, Gallagher, & Workman, 1993), and the ability to plan a project after working on an analogous problem-based challenge (A. Moore, Sherwood, Bateman, Bransford, & Goldman, 1996) all of which are skills needed in real-world contexts.

A more ambitious, longitudinal comparative study by Boaler (1997, 1998) followed students over three years in two British schools that were comparable with respect to students' prior achievement and socioeconomic status but that used either a traditional curriculum or a project-based curriculum. The traditional school featured teacher-directed whole class instruction organized around texts, workbooks, and frequent tests in tracked classrooms. Instruction in the other school used open-ended projects in heterogeneous classrooms. Using a pre- and posttest design, the study found that students had comparable learning gains when tested on basic mathematics procedures; those who in addition participated in the project-based curriculum did better on conceptual problems presented in the National Exam. Significantly more students in the project-based school passed the National Exam in year three of the study than those in the traditional school. Boaler noted that, although students in

Expeditionary Learning

At King Middle School, in Portland, Maine, which has adopted the Expeditionary Learning Outward Bound model of personalized, project-based learning, celebrations with everyone from parents to community members are an important part of the learning process. At least twice a year, students, who stay with the same group of teachers for two years (a practice called looping), undertake four- to twelve-week interdisciplinary projects, each of which concludes with an event.

Besides incorporating such subjects as art, science, and language arts, the projects include well-considered use of computer technology, which has been aided by the state of Maine's decision to provide all seventh and eighth graders with Apple iBook laptop computers.

Culminating events have come in a number of forms: a performance of an original play; a presentation to younger students of a geology kit; and production of a CD-ROM, book, or video—all of which incorporate state curriculum standards. Projects at King have included an aquarium design judged by local architects; a CD narrative of Whitman's "O Captain! My Captain!" by students learning English; *Voices of U.S.* (a book of immigrant stories); a guide to shore life of Casco Bay; original music composition and production; documentaries on learning with laptops; a claymation video explaining Newton's Laws; a Web site on pollution; and a CD-ROM on Maine's endangered species.

Ann Brown, the eighth-grade science teacher who oversaw the claymation video production, likes the effect of such projects on the students. "I think it makes for an interesting way for kids to represent their learning," she said. "It's a lot more interesting than having them simply write about it or draw pictures of it, because they really have to think about how to communicate with an audience and use text and images that make sense to people who haven't studied what they've studied."

UNDERSTANDING AND REPRESENTATION

"The goal for us at King Middle School is to create opportunities for all kids to do representational work about their learning," stated David Grant, King's technology teaching strategist. He works with both students and teachers to ensure that any video or computer or Web production furthers the curriculum. "It's in the making of things that kids actually do their learning," he said. "When you start to make something, you look at it, you reflect upon it, and you begin to be informed by your own representation. And then in that way, you either go out into the world to get more data to support your ideas or you begin to think about something new in your mind and you start to re-represent. And that's how the learning gets deep."

It's also how one can tell whether students understand the concepts they're talking about. "I'm sitting right down at the computer with the kid and I'm saying, 'Well, how does that show us Newton's Law?' And they might have gotten that answer right on the test. But when you sit down and look at their representation and you hear from them what they're trying to say, and you pull it apart a little bit, you wind up in this space where you really get to see what they know and what they don't know. And that's always where we want to be working from—what they know and what they don't know. And working with these media allows that to happen."

QUALITY LEARNING FOR EVERYONE

Brown likes the fact that video requires students to work in teams and learn from each other. "That adds to the final product because the different angles produce different ways of approaching the same problem. You get pieces of the best ideas coming together, so the final product is that much better, and they're also learning from each other and thinking differently."

King put an end to tracking and special education "pullout" classes at about the same time it adopted the project approach to learning and began emphasizing the use of technology. Since then, test scores have shot up—a major accomplishment for a student population that is 60 percent low-income and 22 percent refugee and that comes to school speaking twenty-eight languages. Following years of below-average scores on the state achievement test, King students began outscoring the state average in six out of seven subjects in 1999, and they even moved into the top third in some subjects.

Principal Mike McCarthy, a National Principal of the Year in 1997, believes that giving all students—not just those at the top of the class—the highest-quality and most challenging education makes the difference at King. "I've heard people describe what a Gifted and Talented classroom would look like. It should include field experiences. It should include technology. It should include independent work. It should include work that's in-depth. That's basically what our school is. Everyone has access to that kind of learning."

The close relationship of students and their families with teachers through looping also plays a significant role in students' success, McCarthy added. "That means they can get heavily invested in each other. And I think that's part of the reason we produce such great work. One kid said a few years ago, 'Nobody feels stupid around here anymore.' I think that was one of our highest achievements."

MORE INFORMATION

- A video on King Middle School's Expeditionary Learning program can be seen at www.edutopia .org/expeditionary-learning-maine-video.
- For more on the Expeditionary Learning Schools Outward Bound model, go to www.elschools.org.

Adapted from Edutopia article "Laptops on Expedition: Embracing Expeditionary Learning," by Diane Curtis. Originally published Jan. 19, 2004.

the traditional school "thought that mathematical success rested on being able to remember and use rules," the PBL students had developed a more flexible, useful kind of mathematical knowledge that engaged them in "exploration and thought" (Boaler, 1997, p. 63).

Another comparative study came about as part of an independent evaluation of a five-year project that created opportunities for students to develop multimedia projects. The Challenge 2000 Multimedia Project in Silicon Valley involved students on a variety of projects that led to presentations of their work at regional fairs. To assess the effectiveness of these experiences, researchers created an additional performance task that asked these students and a comparison group to develop a brochure informing school officials about problems faced by homeless students (Penuel, Means, & Simkins, 2000). The students in the multimedia program earned higher scores than the comparison group on all three measures derived from the design task: content mastery, sensitivity to audience, and coherent design. There were no differences on standardized test scores of basic skills.

Many other studies have recorded student and teacher reports of positive changes in motivation, attitude toward learning, and skills as a result of participating in PBL, including work habits, critical thinking skills, and problem-solving abilities (see, e.g., Bartscher, Gould, & Nutter, 1995; Peck, Peck, Sentz, & Zasa, 1998; Tretten & Zachariou, 1995). Some have found that students who do less well in traditional instructional settings excel when they have the opportunity to work in a PBL context, which better matches their learning style or preference for collaboration and activity type (see, e.g., Boaler, 1997; Meyer, Turner, & Spencer, 1997; Rosenfeld & Rosenfeld, 1998). One interesting study observed four PBL classrooms in the fall and spring of a school year, finding much larger increases in five critical thinking behaviors (synthesizing, forecasting, producing, evaluating, and reflecting) and five social participation behaviors (working together, initiating, managing, intergroup awareness, and intergroup initiating) for initially low-achieving students over the course of the year than for initially high-achieving students (Horan, Lavaroni, & Beldon, 1996).

Problem-Based Learning

Problem-based learning approaches are a close cousin of project-based learning and are often configured as a specific type of project that aims to teach problem definition and solution strategies. In problem-based learning, students work in small groups to investigate meaningful problems, identify what they need to learn in order to solve a problem, and generate strategies for solution (Barrows, 1996; Hmelo-Silver, 2004). The problems are realistic and ill structured, meaning that they are not perfectly formulated textbook problems but rather are like those in the real world with multiple solutions and methods for reaching them. In addition, research that has sought to establish the characteristics of "good" problems suggests that they should resonate with students' experiences, promote argumentation, foster opportunities for feedback, and allow repeated exposure to concepts.

Much work on this approach has been associated with medical education. For example, physicians-in-training are presented with a patient profile, including a set of symptoms and a history, and the small group's task is to generate possible diagnosis and a plan to differentiate possible causes by conducting research and pursuing diagnostic tests. The instructor typically plays a coaching role, helping to facilitate the group's progress through a set of activities that involve understanding the problem scenario, identifying relevant facts, generating hypotheses, collecting information (interviewing the patient, ordering tests), identifying knowledge deficiencies, learning from external resources, applying knowledge, and evaluating progress. The steps in the cycle may be revisited as work progresses (for example, new knowledge deficiencies may be noticed at any point and more research might be carried out). Meta-analyses of studies of medical students have found that, across studies, students who are enrolled in problem-based curricula score higher on items that measure clinical problem solving and on actual ratings of clinical performance (Albanese & Mitchell, 1993; Vernon & Blake, 1993).

Similar problem- or case-based approaches have been used in business, law, and teacher education to help students learn to analyze complex, multifaceted situations and develop knowledge to guide decision making (see, e.g., Lundeberg, Levin, & Harrington, 1999; Savery & Duffy, 1996; S. M. Williams, 1992). This method of learning is guided in part by our understanding of the important role of analogy in learning and transfer (Gentner & Markman, 1997; Holyoak & Thagard, 1997; Kolodner, 1997). In complex domains, reasoning by analogy to familiar cases is an important strategy for making sense of new situations.

In all problem-based approaches, students take an active role in knowledge construction. The teacher plays an active role in making thinking visible, guides group process and participation, and asks questions to solicit reflections. The goal is to model good reasoning strategies and support the students to take on these roles themselves. At the same time, teachers also offer instruction in more traditional ways such as lectures and explanations crafted and timed to support inquiry. In a case study of an expert problem-based learning teacher/facilitator, Hmelo-Silver and Barrows (2006) found that the teacher's primary means of shaping the groups' progress was through questioning that helped focus students' attention and supported generation of causal explanations. Continued questioning helped students create accurate mental models of the patient's condition and pushed them to link their hypotheses to the patient's symptom profile. It is of note that in medical school settings each group often has continued access to a facilitator. In most K–12 schools, a single teacher has to find ways to move from group to group, making this approach more challenging.

Studies of the efficacy of problem-based learning suggest that, like other project-based approaches, it is comparable, and sometimes superior, to more traditional instruction in facilitating factual learning, but it is better in supporting flexible problem solving, application of knowledge, and hypothesis generation (for a meta-analysis, see Dochy, Segers, Van den Bossche, & Gijbels, 2003). Additional quasi-experimental studies have demonstrated that students who participate in problem-based experiences generate more accurate hypotheses and more coherent explanations (Hmelo, 1998b; Schmidt et al., 1996), are more able to support claims with well-reasoned arguments (Stepien et al., 1993), and show larger gains in conceptual understanding in science (D. C. Williams, Hemstreet, Liu, & Smith, 1998).

These gains and others have been identified in a line of research undertaken by the Cognition and Technology Group at Vanderbilt University over more than a decade. In one early study, for example, more than seven hundred students from eleven school districts engaged in a set of problem-based projects through the Jasper series, which presents videotaped problems that include a package of information to be used in solving problems that are posed. For the five sites that employed matched control groups, the researchers determined that participants experienced larger gains than the comparison students in all five areas measured: mathematics concepts, word problems, planning capabilities, positive attitudes about mathematics, and teacher feedback.

Design-Based Learning

A third genre of instructional approaches has grown out of the idea that children learn deeply when they are asked to design and create an artifact that requires understanding and application of knowledge. It is believed that design-based projects have several features that make them ideal for developing technical and subject matter knowledge (Newstetter, 2000). For example, design activity supports revisions and iterative problem solving as projects require cycles of

defining → creating → assessing → redesigning

The complexity of the work often dictates the need for collaboration and distributed expertise. Finally, a variety of valued cognitive tasks are employed such

Tomorrow's Engineers—Building a Competitive Robot

Every spring, thousands of students meet at regional events to put their creations through their paces in a competition that, like many others, involves teamwork, problem solving, and perseverance—but unlike some, imagination, creativity, professionalism, and maturity as well. The students who participate in the annual FIRST Robotics Competition (FRC), and their mentors, also tend to have a lot of fun.

Started by engineer and inventor Dean Kamen, FIRST (For Inspiration and Recognition of Science and Technology) is about inspiring and motivating students to become engaged in math, science, engineering, and technology. Each year, teams of students, teachers, sponsors, and professional engineers respond to the FIRST challenge by designing and building a robot.

"To passively sit in a classroom is a nineteenth-century format," Kamen has said. "In this next century, you're going to have to be creative, or you're not going to make it."

HANDS-ON SCIENCE AND ENGINEERING

The regional and final national competitions are the culmination of six intense weeks during which students, working with high school teachers and professional engineers, design and build a remote-control robot from a standard kit of hundreds of parts. The robot must be able to complete specific tasks and maneuver through a specially designed course—both of which change every year. More than ten thousand students, on thirteen hundred teams from twenty-three countries, competed in the various FIRST competitions in 2007. (In addition to FRC, there is a competition for nine-to-fourteen-year-olds and another for high school students that uses a smaller, more accessible parts kit.)

"Mentoring plays a big role in the process right from the start," says Lori Ragas, senior teams coordinator for FIRST. From the first brainstorming session to the last match at one of the regionals or the national competition, professional engineers work side-by-side with the high school students, explaining the functions of different parts, providing feedback on design options, and rolling up their sleeves to repair a faulty part or tinker with a design element.

A recent winner of the engineering design award, the team from Poudre High School, in Fort Collins, Colorado, devoted the first week and a half after announcement of the design challenge to what teacher and robotics coach Steve Sayers called "pure strategy," where everyone—from the first-year participant to the veteran team member, from parents to professional engineers—put forth design ideas. From those best ideas came a basic design, which the team spent the next five weeks refining, fabricating, and testing on a prototype of the actual competition course.

Although much of the work each year revolves around design and engineering, Sayers, who was a chemical engineer before making the switch to teaching, pointed out that a successful team requires an eclectic mix of students with a variety of skills and interests.

"If a student wants to be on the team, the first questions I ask them are, 'What do you enjoy doing? What are you good at?'" said Sayers, adding that there's "something for everyone" on the Poudre High robotics team. Students interested in computers do the programming or computer-aided design and animation work. Those with artistic abilities design everything from team T-shirts to flyers to the look and feel of the robot itself. Writers create the design documentation. The list of responsibilities goes on and on. No one job, Sayers was quick to add, is more important than any other.

"Everyone is an equal part of the team," he said. "We all just respect each other for the different roles we play."

SKILLS FOR THE FUTURE

Mark Leon, NASA's robotics education project manager, has been working with high school robotics teams since 1998. NASA's reason for supporting robotics education (both financially and by providing mentors to schools throughout the country) is simple: "We need to build robots that are smarter, robots that can survive for long periods of time without being in communication with NASA," Leon said. "We're getting these students excited about robotics engineering, helping them to choose math and technology careers so they can contribute back to this country, so they can be part of the workforce that builds the next generation of robotic explorers."

But the benefits to students—and to any future employers—go beyond the science and engineering skills students gain from participating in the program. Respect, cooperation, and learning to be a team player are just a few of the life skills students learn through the robotics program. Those are skills, team members and adult advisers agree, that students will carry with them, whatever career they choose.

Janet Tsai, who was on the Poudre High team for two years, put it this way: "We're all working towards a common goal. And to get to that common goal, we all need to work together and listen to everyone's ideas. You can't just remain contained in your own little bubble and hope that everyone else knows what's going on too."

Tyson Wormus, a three-year veteran of the Poudre High team, had a similar experience. "I've become a lot more confident through the work with this program," he said. "I can present ideas without many qualms, and I've learned to listen to other people's ideas."

For students like Tsai, participation in the FIRST program affords an up-close look at what life as an engineer is all about. "The hands-on experience I gained from working on this project has just been absolutely phenomenal," she said. "It's really neat the way the students design and fabricate the robot. It really shows you what you can do." Because of her participation in FIRST, Tsai said, she is considering majoring in science or engineering when she gets to college.

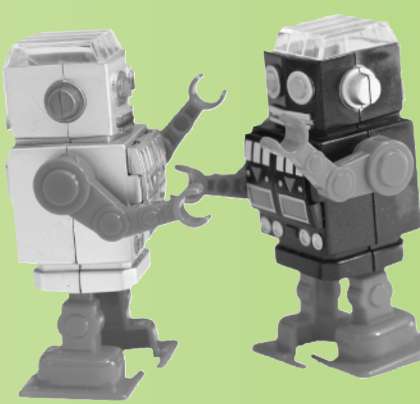
Tsai is not unusual in her reaction. A recent survey of FIRST Robotics Competition participants concluded that, relative to a comparison group of non-FIRST students with similar backgrounds and academic experiences (including math and science), they are:

- Far more likely to attend college full time (88% vs. 53%)
- More likely to expect to earn at least a master's degree (77% vs. 69%)
- Roughly 10 times as likely to have an apprenticeship, internship, or co-op job as a college freshman (27% vs. 2.7%)
- Twice as likely to major in science or engineering (55% vs. 28%)

Source: "More than Robots: An Evaluation of the FIRST Robotics Competition Participant and Institutional Impacts." Prepared by Alan Melchior, Faye Cohen, Tracy Cutter, and Thomas Leavitt, Center for Youth and Communities, Heller School for Social Policy and Management, Brandeis University, Waltham, Massachusetts (http://www.usfirst.org/uploadedFiles/Who/Impact/Brandeis_Studies/FRC_eval_finalrpt.pdf, accessed Oct. 22, 2007)

MORE INFORMATION

- A video about Poudre High School's 2001 Robotics Team can be seen at www.edutopia.org/poudre-high-school-robotics.
- For more on the FRC and other FIRST competitions, visit www.usfirst.org.



Adapted from Edutopia article "Building a Better Robot: A Robotics Competition Introduces Students to Engineering," by Roberta Furger. Originally published Dec. 3, 2001.

Nonschool-based projects, such as the FIRST robotics competitions, stress student teamwork and strategy

as setting constraints, generating ideas, prototyping, and planning through storyboarding or other representational practices. These are all critical twenty-first-century skills.

Design-based approaches can be found in science, technology, art, engineering, and architecture. Nonschool-based projects organized around contests such as the FIRST robotics competitions (www.usfirst.org) or the Thinkquest competition (www.thinkquest.org) also stress design using technological tools and collaborative project work. For example, Thinkquest is an international competition in which teams of students from nine to nineteen years old come together to build Web sites designed for youth about an educational topic. Teams of three to six are mentored by a teacher who gives general guidance throughout the several months of the design process but leaves the specific creative and technical work to the students. Teams receive and offer feedback during a peer review of the initial submissions, and then they use this information to revise their work. To date, more than thirty thousand students have participated; there are currently more than fifty-five hundred sites available in the online library (http://www.thinkquest.org/library/). Topics range from art, astronomy, and programming to issues such as foster care or use of humor for mental health; almost anything is fair game.

Despite the wide range of applications of learning through design, much of the research-based curriculum development and assessment has taken place in the domain of science (Harel, 1991; Kafai, 1994; Kafai & Ching, 2001; Lehrer & Romberg, 1996; Penner, Giles, Lehrer, & Schauble, 1997). For example, a group from the University of Michigan has been developing an approach called Design-Based Science (Fortus, Dershimer, Marx, Krajcik, & Mamlok-Naaman, 2004), and a Science by Design series that includes four high school units focused on constructing gloves, boats, greenhouses, and catapults. A separate group from the Georgia Institute of Technology has been developing an approach they call Learning by Design, also used in science (Kolodner, 1997; Puntambekar & Kolodner, 2005).

Within the relatively small body of research that uses control group designs, the research on learning reported by Kolodner and colleagues (Kolodner, Camp, et al., 2003) shows large and consistent differences between the Learning by Design (LBD) classes and their comparisons. Their measures assess groups' ability to complete performance tasks before and after instruction. Each task has three parts: (1) students design an experiment that would constitute a fair test; (2) they run an experiment and collect data (the design is specified by the researchers; and (3) they analyze the data and use them to make recommendations. The researchers also score group interaction from videotaped records on seven dimensions: negotiation during collaboration, distribution of the work, attempted use of prior knowledge, adequacy of prior knowledge, science talk, science practice, and self-monitoring. They report that the Learning by Design students consistently outperform non-LBD students on collaborative interaction and aspects of metacognition (for instance, self-monitoring).

In another design experiment that included a comparison sample, Hmelo, Holton, and Kolodner (2000) asked sixth-grade students to design a set of artificial lungs and build a partially working model of the respiratory system. They found that the design condition led to better learning outcomes than students exposed to traditional instruction. They also noted that the design students learned to view the respiratory system more systemically and understood more about structure than function, and more about the functions of the system than causal behaviors. They argue that design activities are particularly good for helping students develop understanding of complex systems because they can be presented as a united whole whose structure is adapted

Build San Francisco Institute: Immersing Students in Civic Education

The Build San Francisco Institute, a yearlong design program co-sponsored by the Architectural Foundation of San Francisco (AFSF) and the San Francisco Unified School District (SFUSD), has as one of its core principles that subjects such as math, history, and writing have a larger context; they are essential tools for conceptualizing, understanding, sketching, and building relevant and compelling real-world projects. "In a military academy, they don't teach trigonometry; they teach navigation," explained Build SF co-founder Richard Hannum. "Because you need trig for navigation, you learn it."

A BRIDGE TO THE REAL WORLD

Offering accredited courses with titles such as Architectural Design and Urban Sociology, today's Build SF is the offshoot of an after-school and summer program launched thirteen years ago. In 2004, as a part of the SFUSD's Secondary School Redesign Initiative, the program was expanded to an all-afternoon, five-day-a-week schedule; two of those days are devoted to working with mentors from some of San Francisco's leading architecture, interior-design, engineering, and contracting firms, along with certain city agencies involved in urban planning.

The curriculum was designed to develop student interest in architecture-related fields and, more fundamentally, to immerse them in the process of meshing civic and business interests. "It's not about building little architects," said Hannum, a Bay Area design-firm principal as well as one of AFSF's founders. "Rather, we use architecture as a vehicle to give kids with no community context an insight into, and a voice in, the public process."

The ability to provide a bridge between education and business is why Janet Schulze, principal at San Francisco's John O'Connell High School of Technology, is a Build SF booster. The program, she said, "is the fastest way to integrate academic skills into a real-world setting."

Schulze praised the effort San Francisco's design community dedicates to the program, particularly in terms of offering mentorships. "I'd love to see the medical and finance communities do something like it," she added.

"STUDIO" MEANS STUDY

At Build SF's downtown studio, the decibel level is much higher than what would be acceptable in most high school classrooms. "This place does develop a certain hum," admitted Alan Sandler, the foundation's executive director. "It's supposed to be like a busy office." AFSF programs director

Will Fowler characterized the ambience as "the real sound of learning. It shocks and delights them that they are encouraged to talk to each other."

Use of the term *studio* rather than the word *classroom* is also not accidental. According to Fowler, "We want the kids to understand that Build SF is more a design studio than it is a school."

None of this is to say that this early part of the school year isn't anarchic for both pupils and teachers. "It's always frustrating at the beginning," Hannum said. "It takes kids time to get over the idea that they have to raise their hands to speak. I tell them, 'We're not in class. We're adults, and if you have something to say, say it.'" Fowler believes it takes about six weeks for the lessons to begin to sink in. "By January," he says, "they will be a well-oiled machine."

Build SF's insistence on treating kids like adults also takes getting used to on the instructional side. Accustomed to dealing with hundreds of kids in a traditional high school setting, Boston-area refugee Casey Brennan admitted she was nervous in 2005 when she began instructing at Build SF. "We were trained never to leave kids alone. When Will Fowler first told me to walk away, it was difficult."

"There is only one rule," Fowler explained. "When Casey says, 'Listen up,' they have to listen up."

RISING TO CHALLENGES

Another central precept of Build SF is that participants be exposed to the unvarnished realities of life in the highly competitive and often-contentious world of design and architecture. One recent project involved creating a series of historically themed tiles for the city's newly redesigned Pier 14. The students had to first design the tiles and then present and "sell" their ideas to the Port Commission—a process that took several iterations, and not a little frustration, before the commission was satisfied. Then the Build SF team had to master the complex process of tile production, from drawing, tracing, and painting to glazing and firing, as well as overseeing installation.

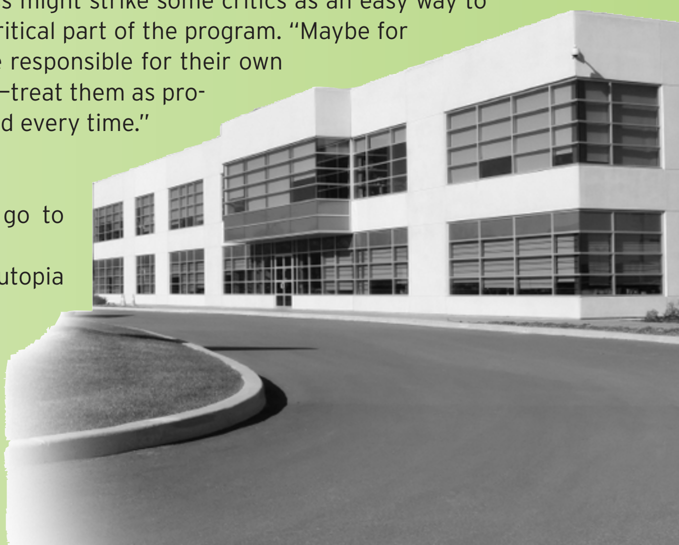
The class also had to realistically assess the talents of each member and assign tasks accordingly. Some of the students less accomplished as artists or designers came into their own as key team leaders whose organizational skills could help the project advance—"our version of middle management," Fowler said with a smile.

Some projects, such as designing and building a bridge with sets of Lego blocks, are meant to get kids from different schools comfortable with one another. "Students tend to spend their entire school careers with the same kids from the same neighborhoods," the AFSF's Sandler said about the goal of opening up new vistas. "When they come here and leave their baggage behind, they're able to develop a different, adult persona."

Comings and goings at the Build SF studio go on throughout the afternoon as students arrive from their morning high school classes, go to work on their various projects, or move on to their assigned mentorships. Some stay all afternoon; others depart for after-school activities at their respective high schools. This open-endedness might strike some critics as an easy way to ditch school. For the Build SF team, however, it is a critical part of the program. "Maybe for the first time in their school careers, kids have to be responsible for their own time," Sandler said. "Our key motto is 'Trust the kids'—treat them as professionals, and they will rise to the challenge each and every time."

MORE INFORMATION

- For more on the Build San Francisco Institute, go to www.afsf.org/program_buildsf.htm.
- A video on the program can be viewed at www.edutopia.org/learning-design.



to specific purposes (Perkins, 1986). Echoing the findings of other classroom research, Hmelo and colleagues (2000) argue that design challenges need to be carefully planned. In this case they argue they should be designed functionally, and they stress the importance of dynamic feedback, allowing students to engage in multiple iterations of design, and giving adequate time to the entire system of classroom activities. In particular, they suggest that teachers working on design projects pay attention to:

- Finding a balance between having students work on design activities and reflecting on what they are learning, so that they can guide their progress. Incorporating reflective activities is important to encourage an understanding-based approach.
- Learning how to integrate real-world knowledge without letting it overwhelm the class with irrelevant aspects of the world that might take the students on unproductive tangents.
- Determining how to maintain extended engagement in a manner that emphasizes principled understanding rather than completion.

Much of the research on learning through design-based projects has been less experimental and more naturalistic, either focused on single-case pre- and postresearch designs or longer-term design experiments where close observation of learning processes and outcomes is accompanied by changes to the curriculum or additions of support for its implementation. For example, Fortus and colleagues (2004) carried out a study with ninety-two students that tracked their learning across three Design-Based Science units. Their units included designing a structure for extreme environments, designing environmentally friendly batteries, and designing safer cell phones. Each unit contained multiple design and learning cycles. The research team found that both higher- and lower-achieving students showed strong evidence of progress in learning the targeted science concepts, and that students applied the concepts well in their design work. They also noted a positive effect on motivation and sense of ownership over designs at both individual and group levels.

Unfortunately, because there was no control group, it is difficult to make strong claims about the relative efficacy of this approach compared to more traditional approaches.

The Cognition and Technology Group at Vanderbilt also documented strong gains in learning for students in a five-week design project aimed at teaching basic principles of geometry in the context of architecture and design (Barron et al., 1998). Students were asked to help design a playground and then create two- and three-dimensional representations for a playhouse they would explain in public presentation to experts. Students of all ability levels made significant gains in their ability to use scale and measurement concepts on their blueprints and to answer traditional test items measuring scale, volume, perimeter, area, and other geometric concepts. Of the thirty-seven designs submitted, 84 percent were judged accurate enough to be built, a result considered a high rate of achievement. (See the box "Successful Inquiry Learning Guided by Design Principles" [p. 57] for a description of the project and how it was supported.)

Design programs build bridges between education and the business world

CHALLENGES OF INQUIRY APPROACHES TO LEARNING

Many challenges have been identified with management of project-based, problem-based, and design-based learning opportunities, as the pedagogies required to implement these approaches are much more complex than teachers' direct transmission of knowledge to students via textbooks or lectures. In fact, inquiry approaches to learning have frequently been found to be highly dependent on the knowledge and skills of teachers engaged in trying to implement them (Good & Brophy, 1986). When these approaches are poorly understood, teachers often think of inquiry or other student-centered approaches as "unstructured," rather than appreciating that they require extensive scaffolding and constant assessment and redirection as they unfold.

Research on these approaches signals a number of specific challenges that emerge when students lack prior experience or modeling regarding particular aspects of the learning process. With respect to disciplinary understanding, students can have difficulty generating meaningful questions or evaluating their questions to understand if they are warranted by the content of the investigation (Krajcik et al., 1998), and they may lack background knowledge needed to make sense of the inquiry (Edelson, Gordon, & Pea, 1999). With respect to general academic skills, students may have difficulty developing logical arguments and evidence to support their claims (Krajcik et al., 1998). As for management of the work, students often find it hard to figure out how to work together, manage their time and the complexity of the work, and sustain motivation in the face of setbacks or confusion (Achilles & Hoover, 1996; Edelson et al., 1999).

In design projects, students take ownership of their education and it becomes more meaningful to them

Teachers may also encounter challenges as they try to juggle the time needed for extended inquiry, learn new approaches to classroom management, design and support inquiries that illuminate key subject matter concepts, balance students' needs for direct information with their opportunities to inquire, scaffold the learning of many individual students, offer enough (but not too much) modeling and feedback for each one, facilitate learning among multiple groups, and develop and use assessments to guide the learning process (Blumenfeld et al., 1991; Marx et al., 1994, 1997; Rosenfeld & Rosenfeld, 1998; Sage, 1996).

Without supports to learn these complex skills, teachers may be unable to use inquiry approaches to learning to their best advantage, engaging students in "doing" but not necessarily in disciplined learning that has a high degree of transfer.

How Can Teachers Support Productive Inquiry?

Clearly, successful inquiry-based approaches require planning and well-thought-out approaches to collaboration, classroom interaction, and assessment. Some research has focused especially on how to support these approaches well. For example, Puntambekar & Kolodner (2005) describe two studies designed to advance our understanding of the kinds of support students need to learn content in the context of design projects. They knew from earlier classroom research (Gertzman & Kolodner, 1996) that simply furnishing students with rich resources and an interesting problem (say, design a household robot with arthropod features) was not enough. Students needed help understanding the problem, applying science knowledge, evaluating their designs, explaining failures, and engaging in revision. Students often neglected to use informational resources unless explicitly prompted.

To address these problems, the researchers introduced a design diary that was intended explicitly to introduce design process ideas and to support four phases of design work: understanding the challenge, gathering information, generating a solution, and evaluating solutions. The goal of the eighth-grade, three-week curriculum was to help students learn about coastal erosion. Students were given a challenge of designing a solution to this problem for a specific coastal island off the coast of Georgia. To experiment with solutions, they had access to stream tables as well as informational resources on videotape and the Internet. In addition to implementing the journal, they carried out careful assessment of students' learning and observation of classroom interactions. In this first study, the learning outcomes were disappointing. However, the researchers' insights about how to support students were generative.

For example, they noted that the teacher missed many opportunities to advance learning because she could not listen in to all small group discussions and had decided not to have whole group discussions. They also noted that the students needed more specific prompts for justifying design decisions.

In the second study, they designed and implemented a broader system of tools and processes, which greatly improved the learning outcomes—notably, more structured diary prompts that asked for design rationales and explanations, and insertion of whole class discussions at strategic moments. They also added new activity structures that required students to publicly defend designs earlier in the process; they called these "pin up sessions," drawing on ideas from architectural studio learning. In these sessions, students present their ideas by pinning their drawings of their design plans to the wall as a poster and then explaining them to the class in order to get feedback. For each idea, students were asked to give a justification from informational resources or experimental evidence they themselves collected (Kolodner et al., 2003; Puntambekar & Kolodner, 2005). These processes of helping students keep track of and defend their thinking were very helpful. In addition, the *redundancy* of learning opportunities afforded by the several forms of support was a key in helping students focus on learning concepts and connecting them with their design work.

The playground design project described earlier (Barron et al., 1998), which used a combination of problem-based, project-based, and design-based learning approaches, generated an additional set of design principles:

- Define learning-appropriate goals that lead to deep understanding
- Offer scaffolds that support both students' and teacher's learning
- Ensure multiple opportunities for formative self-assessment and revision
- Design social organizations that promote participation and result in a sense of agency

Application of these principles is described in the box "Successful Inquiry Learning Guided by Design Principles."

SUCCESSFUL INQUIRY LEARNING GUIDED BY DESIGN PRINCIPLES

A curriculum project featuring multiple activities was developed by the Cognition and Technology Group to develop fifth-grade students' mathematical problem-solving ability, representational capacities, and understanding of concepts such as area and scale. The sequence began with a design challenge presented in the context of a video-based anchor from the Jasper series. In this series, fifteen-minute videos were encoded on videodisks, featuring narratives ending with *problem-solving challenges* that could be addressed by data embedded in the movie. This design invited students to formulate problems, find relevant data, and generate quantitative methods to solve them (CTGV, 1997). In addition, embedded within the fifteen-minute narrative were explanations that gave ideas for how to approach problems that supported teachers' and students' knowledge building. These carefully designed, video-based problems modeled aspects of inquiry and encouraged development of key subject matter knowledge. They were followed by thematically related, real-world projects that students could implement as a means of deepening their learning and engaging their motivation.

In one version of this sequence, the goal for students was to learn about measurement, drawing to scale, and how to produce drawings that someone could build from. Students begin by solving a challenge presented in "Blueprint for Success." In Blueprint for Success they meet two students, Christina and Markus, who visit an architect's office for career day. The story begins with a dramatic scene in which a friend is playing in the street and is hit by a car. Although the accident was not serious and the friend is going to be fine, the incident prompts a local developer to donate land. The developer comes to the architect's office while Christina and Markus

(continued)

are visiting. Christina and Markus suggest that a playground be built on the donated property to create a fun spot for children to play. The developer agrees with this idea and invites the children to design the equipment and park layout, and to complete the needed blueprints. The story ends with a summary of the materials that have been donated by the local businesses and a challenge to children in the classroom to develop the plan. Specifically the challenge is to:

- Create a design or model of the playground for the builders
- Make a site plan of the lot, the playground, and each piece of equipment
- Generate a front and side view of the equipment with relevant angles, lengths, and depths

At the end of the story, students find out that community organizations and businesses have agreed to donate building supplies, including 280 feet of fence, 32 cubic feet of sand, sliding boards for a slide, and all the wood and fine gravel to cover the lot. The students are asked to specify how much wood, gravel, and sliding board they will need. In addition, students are given a list of safety requirements that detail appropriate ranges of angles, depth of gravel needed, and distances required between pieces of equipment. These materials and safety requirements then become constraints for students to attend to as they complete their designs.

Reflecting the first design principle, the learning goals and activities are closely aligned. To succeed in this challenge, students must resolve issues such as what it means to draw to scale; how to maximize area, given constraints on perimeter; and figure out how to create blueprints of equipment that show the measurements of all the relevant dimensions. Their playground scale drawings are assessed and revised through several cycles, and their subject matter learning is supported through a variety of multimedia resources created specifically to address particular concepts such as scale, area, and volume.

Only after each member of the group has demonstrated mastery of these concepts through his or her playground design is the student allowed to continue on to the next phase where the design activity might result in an actual product. For the project-based component, students are asked to design a play structure for a local community center. From the outset of the problem-based work, children are aware that their work on "Blueprint" is preparing them to design a playhouse for young children that may actually be built and donated to community centers in local neighborhoods; there is considerable excitement generated by the idea that their design might actually end up being used by young children. Students also know that for their design to have a chance of being built they must make an accurate blueprint and scale model. Specific design constraints for the playhouse are imposed:

- Children who are four and five years old will play in it.
- Only two sheets of wood, each 4 feet by 8 feet, can be used to build the playhouse. The walls, roof, and trim must all come from this wood. The design should use as much of the two sheets of wood as possible.
- The playhouse must have three walls and a flat roof.
- The floor space that the playhouse covers must be between 10 and 20 square feet.
- Any openings for doors and windows must be safe. They must be larger than 7 inches or smaller than 4 inches to prevent children from putting their head into an opening and getting stuck. There should not by any V-shaped openings.

Finally, students are told that they will explain the blueprints and scale models they create on videotape so that they can be evaluated for accuracy and consistency with problem constraints. The evaluators in this case are not their teachers but an outside audience known as "Jasper Central." This structure frees the teacher to join with the students and serve in the role of coach. The final presentation is an important aspect of the projects. It gives students an opportunity to reflect on issues such as what it means to explain one's thinking, and how to convince someone of the accuracy of a plan, as well as issues such as what makes a presentation engaging. The guidelines for the presentation:

- Every member of your group must speak during the presentation.
- The presentation should be five to ten minutes long.

(continued)

- You must convince Jasper Central of the following:
    - The design uses as much of the available wood as possible, but no more than the available wood. The playhouse is safe for four- and five-year-old children. The playhouse is fun to play in. Use your imagination and be creative.
- Students spent approximately one week designing their playhouses, preparing their blueprints, and developing their presentations. The presentations are evaluated for accuracy, safety, and consistency, and for how well they communicate important design features. Here is an example of one group's presentation.

PRESENTATION OF FINAL PLAYHOUSE DESIGN MODELS

All three presenters in unison: Good morning, students.

Presenter one: Hello, I'm Mr. Robert. I'm going to talk about the blueprint today. First I'd like to say, we started out with 4 by 8 pieces of plywood so each wall should by 4 by 4, 4 feet across and 4 feet up. Our scale is 6 inches for one block [points to scale on blueprint]. Now I'll talk about the front. The window is 9 inches across and 1 foot down. So, that should mean that there is a block and a half going across and there are two blocks going down. That's the same for this one. Now I'll talk about the door. The door is 3 feet high, so it should be six blocks up, and three blocks across. Now the side views. Both of them have two windows, 1 foot going across and 1 foot going up. Also, I'd like to talk about the extra wood. The extra wood in the parenthesis means how many there is. It shows it right here, they're in the windows. Like this: there's four of them, it shows it right here. And then right here it can show that there are two of them right here and right here [points to two window spaces], and then, like this big space, this is the door, it shows that it has one of these, and then the number tells the number of them so you can look right here at the parts that are extra wood and you can find where these are. Now I put "important" by this right here, I put the shutters, are 3 inches each, um, so the architect would know um, how long to paint um, how long to draw um. Thank you.

Presenter two: Hi, I am Mr. Sircar and I'm here to talk to you about our front view and top view. Let's start off with our window; you can see that our window has been 9 inches wide and 1 foot long, on both. The reason we picked 9 inches is because, so children could stick out their heads and, and see out, see outside, and so they would not get their head stuck, and because, the requirement sheet said that any openings would have to be more wider than 7 inches. Now, see our door. Our door has been 2 feet wide and 3 feet long. The reason we picked 2 feet wide is so that children wouldn't have to squeeze in, and the reason we picked 3 feet long is because so children wouldn't have to duck. . . . Now you can see that our top view has been just four by four [picks up three-dimensional scale model and orients top to audience]. . . . You can see there has been grass, pencils, a school, and a flag. The way we got those extra pieces of wood has been from our seven holes, One, two, three, four, five, six, seven [turns music stand to show audience each as he counts]. We got those extra pieces from our extra plywood, our grass, our pencils, the name of the school, and our flag. Thank you.

Presenter three: Hi, my name is Mrs. Duncan, and y'all already met me today. Now, I'm going to talk about our left side, our right side of our school house. We have grass that is green and we have windows, and we got shutters from this extra credit, extra wood [points to blueprint]. And now I am going to talk about left side. We have grass green, we have extra wood again [points to blueprint where extra wood is detailed], and we have windows. I'm going to talk about why we built our school house. We built our school house for ages four- and five-year-old children. They can play school, learn, and do all kinds of other things. Thank you.

In unison: Class dismissed!

The system of activities, assessments, and resources described here reflects the four design principles. First, learning-appropriate goals that lead to deep understanding were defined. Both the problem-based and project-based activities required and supported specific mathematical concepts. Second, multiple types of scaffold that could support both student and teacher learning were provided through the embedded teaching sequences within "Blueprint for Success" and through extra resources that illustrated concepts of scale, volume, and related concepts. Third, there were multiple opportunities for formative self-assessment and revision given to both individuals and groups. Students' drawings were scored, and they were revised until they had met a standard of accuracy. Fourth, motivation, a sense of agency, and continued engagement were supported by collaborative structures, a chance to design something that might be built, and the opportunity to present to an outside audience supported.

This project-based learning planner assists teachers in their efforts to create effective projects. The guide came from LEARN, a nonprofit educational foundation based in Quebec.

PBL Project Planner

I ASK MYSELF . . .	ANSWER
Vision stage:	
1. What are my subject/learning objectives?	1.
2. What are my interdisciplinary subjects and competencies?	2.
3. What inquiry question/investigation will meet no. 1, no. 2?	3.
Inquiry stage:	
1. How will I hook or trigger the student's interest in the inquiry question? What scenario will I use?	1.
2. What kinds of information can I expect to be brought out of our class brainstorming session? What kind of misconceptions do I expect to encounter?	2.
3. What rubric(s) will I use? Will I design it myself or with my students?	3.

I ASK MYSELF . . .	ANSWER
Build stage:	
1. How will I organize the brainstorming session? How will we categorize and sort the information we come up with?	1.
2. What kind of teams will work best for this project? (i.e., number of members, roles, responsibilities)	2.
3. What information and computer technologies are necessary in order to accomplish these tasks? Do I need to review or teach any of these skills?	3.
4. What research techniques will we need? Do I need to review or teach any?	4.
5. What kind of final products would lend themselves well to this type of investigation?	5.
6. At what stage will I ask for product updates? What format will these updates be in? (i.e., journal entry, oral presentation, etc.)	6.
Showtime stage:	
What kind of showcase will be most appropriate to display the student's knowledge acquisitions? (i.e., museum display, PowerPoint presentation, play in front of an audience, etc.)	1.
Transition stage:	
Will I ask my students to give an oral reflection or a written reflection of their learning, and thoughts on this project?	1.

Source: LEARN, www.learnquebec.ca.

The Critical Importance of Assessment

As the discussion suggests, collaborative and inquiry approaches to learning require that we consider classroom activities, curriculum, and assessment as a system in which each interdependent aspect is important to an environment that promotes flexible knowledge development. Indeed, our ability to assess—both formatively and summatively—has enormous implications for what we teach, and how effectively. At least three elements of assessment are especially important for meaningful learning of the kind we have been describing:

Designing *intellectually ambitious performance assessments* that define the tasks students will undertake in ways that allow them to learn, and apply the desired concepts and skills in authentic and disciplined ways

Creating guidance for students' efforts in the form of *evaluation tools* such as assignment guidelines and rubrics that define what constitutes good work (and effective collaboration)

Frequently using *formative assessments* to guide feedback to students and teachers' instructional decisions throughout the process

The nature of assessment plays a significant role in shaping the cognitive demands of the work students are asked to undertake. Research suggests that thoughtfully structured performance assessments can support improvement in the quality of teaching, and that inquiry-based learning demands such assessments both to define the task and to properly evaluate what has been learned (Black & Wiliam, 1998b). In addition to finding beneficial influences of performance assessments on teaching practices (Chapman, 1991; Firestone et al., 1998; Herman, Klein, Heath, & Wakai, 1995; Lane et al., 2000; Stecher et al., 1998), some studies have also found that teachers who are involved in scoring performance assessments with other colleagues and discussing their students' work declare the experience helpful in changing their practice to become more problem-oriented and more diagnostic (see Darling-Hammond & Ancess, 1994; Falk & Ort, 1997; Goldberg & Rosewell, 2000; Murnane & Levy, 1996).

A number of studies have found an increase in performance on both traditional standardized tests and performance measures for students in classrooms that offer a problem-oriented curriculum that regularly features performance assessment. For example, in a study of more than two thousand students within twenty-three restructured schools, Newmann, Marks, and Gamoran (1995) found much higher achievement on complex performance tasks for students who experienced what these researchers termed "authentic pedagogy," instruction focused on active learning in real-world contexts calling for higher-order thinking, consideration of alternatives, extended writing, and an audience for student work.

There are many ways in which authentic assessments contribute to learning. For example, exhibitions, projects, and portfolios are occasions for review and revision toward a polished performance. These opportunities help students examine how they learn and how they can perform better. Students are often expected to present their work to an audience—groups of faculty, visitors, parents, other students—to ensure that their apparent mastery is genuine. Presentations of work also signal to students that their work is important enough to be a source of public learning and celebration; they are an opportunity for others in the learning community to see, appreciate, and learn from student work. Performances create living representations of school goals and standards so that they remain vital and energizing, and they develop important life skills. As Ann Brown (1994) observed: "Audiences demand coherence, push for high levels of understanding, require satisfactory explanations, request clarification of obscure points. . . . There are deadlines, discipline, and most important, reflection on performance. We have cycles of planning, preparing, practicing, and teaching others. Deadlines performance demand the setting of priorities—what is important to know? [p. 8]"

Planning, setting priorities, organizing individual and group efforts, exerting discipline, thinking through how to communicate effectively with an audience, understanding ideas well enough to answer the questions of others . . . all of these are tasks people engage in outside of school in their life and work. Good performance tasks are complex intellectual, physical, and social challenges. They stretch students' thinking and planning abilities while also allowing student aptitudes and interests to serve as a springboard for developing competence.

In addition to designing tasks that are intellectually powerful, teachers need to guide students as to the quality of work and interactions they are aiming for. The benefits of clear criteria given in advance have been documented by many studies (for example, Barron et al., 1998). E. G. Cohen and her colleagues tested the idea that clear evaluation criteria could improve student learning by improving the nature of the conversation (Cohen, Lotan, Abram, Scarloss, & Schultz, 2002). They found that introducing evaluation criteria led groups to spend more time discussing content, discussing the assignment, and evaluating their products than groups who were not given criteria. They also found that individual learning scores were significantly correlated with the amount of evaluative and task-focused talk.

The criteria used to assess performances should be multidimensional, representing the various aspects of a task rather than a single grade, and should be openly expressed to students and others in the learning community rather than kept secret in the tradition of content-based examinations (Wiggins, 1989). For example, a research report might be evaluated for its use of evidence, accuracy of information, evaluation of competing viewpoints, development of a clear argument, and attention to conventions of writing. When work is repeatedly assessed, the criteria guide teaching and learning—students become producers and self-evaluators while teachers become coaches. A major goal is to help students develop the capacity to assess their own work against standards, and to revise, modify, and redirect their energies, taking initiative to promote their own progress. This is an aspect of self-directed work and self-motivated improvement required of competent people in many settings, not least a growing number of workplaces.

Use of performance tasks is also important so that we can adequately assess the benefits of problem- and project-based approaches for learning and application of knowledge. For example, Bransford and Schwartz (1999) and Schwartz and Martin (2004) have demonstrated that the outcomes of different instructional conditions might look similar on "sequestered problem solving tasks" but much less so on assessments that gauge students' "preparation for future learning." The preparation for future learning tasks asked students to read new material that was composed to include opportunities to learn. On this kind of task, they found that students who had been in a learning condition where they were first asked to invent a solution to a problem were more likely to learn from the new material than students who had been given traditional instruction consisting of explanations, examples, and practice.

In Table 2 of the Appendix we summarize types of assessment that can be used in long-term inquiry approaches. As the table shows, assessment venues can be construed broadly to include rubrics that are applied to artifacts, whole class discussions, midcourse design reviews, performance assessments, and new transfer problems. The best project-based approaches use a combination of informal ongoing formative assessment and project rubrics that can both communicate high standards and help teachers make judgments about the multiple dimensions of project work. For rubrics to be useful, they must include scoring guides that specify criteria, ideally written for both teachers and students. More research on designing and using such assessments is needed.

Finally, formative assessment is a critical element in learning generally, and it is especially important in the context of long-term, collaborative work. Formative assessment is designed to provide feedback to students so that they can then revise their understanding and their work. It is also used to inform teaching so it can be adapted to meet students' needs. The benefits of formative assessment for learning have been documented in a classic review article (Black & Wiliam, 1998a), which documented that substantial learning gains result from giving students frequent feedback about their learning, especially when that feedback comprises specific comments that can guide students' ongoing efforts.

An important aspect of ongoing assessment is development of students' capacity to assess their own work, so that they internalize standards and become meta-cognitive in their thinking about their own learning. The power of these approaches has been illustrated in many studies (see, e.g., Black & Wiliam, 1998; Magnusson & Palincsar, 2004; Palincsar & Brown, 1984; Paris, Cross, & Lipson, 1984; Schoenfeld, 1992). A useful illustration can be seen in a comparison group study that evaluated the impact of self-assessment on student learning in twelve inquiry-based middle school science classrooms featuring inquiry cycles in which students investigated concepts of force and motion through experiments and computer simulations. The experimental groups used half their time in discussion structured to promote self- and peer-assessment of cognitive goals and processes, while the control group used this time for general discussion of the concept. The study found that students involved in self-assessment showed significantly larger gains on both a conceptual physics test and project scores, and that students with low pretest scores showed the largest gain on all of the outcome measures (Frederiksen & White, 1997). An analysis of formal and informal self-evaluation processes in Australia and England (Klenowski, 1995) concluded that an integrated practice of self-assessment leads students to take a greater responsibility for their own learning, thus cultivating a shift toward intrinsic motivation and internal locus of control.

Research on formative assessment suggests that feedback is more productive when it is focused on student process, rather than product, and keyed on the quality of the work (task-involving) rather than quality of the worker (ego-involving), offering comments instead of grades for students to consider (Black & Wiliam, 1998a; Butler, 1988; Deci & Ryan, 1985). Shepard (2000) suggests that the focus on process and task allows students to see cognitive prowess not as a fixed individual trait but as a dynamic state that is primarily a function of the level of effort in the task at hand (see also Black & Wiliam, 1998a, 1998b). This can support their motivation as they sustain confidence in their own ability to learn.

This is compatible with recent research underscoring the influence of a student's identity as a learner on his or her engagement and approaches to learning. How students see themselves in relation to activities and disciplines can influence the goals they adopt and the strategies they pursue (Boaler & Greeno, 2000; Gee, 2003; Gresalfi & Cobb, 2006; Nasir & Kirshner, 2003). It has been hypothesized that as students become engaged as producers of complex products and organizers of long-term projects, they begin to recognize within themselves capacities that lead them to identify as authors, designers, critical consumers, and analysts (Barron, 2006a, 2006b; Mercier, Barron, O'Connor, 2006). These identities, or possible selves (Markus & Nurius, 1986), in turn can lead to development of learning goals that support continued engagement (Nasir, 2005). The highly engaging nature of inquiry-based approaches is often noted. If these approaches are supported by formative self- and peer-assessments and opportunities for feedback and revision, positive identity construction is reinforced, which may be as important to long-term learning outcomes as near-term knowledge gains (Barron, 2006a, 2006b; Hidi & Renninger, 2006).

It is important to note that there are a set of related practices of importance in the activities we have described: integration of assessment and instruction, systematic use of iterative cycles of reflection and action, and ongoing opportunity for students to improve their work. The practices are grounded in a conception of learning as developmental and a belief that all students will learn from experience and feedback, rather than being constrained by innate ability. As Black and Wiliam (1998a) remark of one of the studies they reviewed:

> An initiative can involve far more than simply adding some assessment exercises to existing teaching—in this case the two outstanding elements are the focus on self-assessment and the implementation of this assessment in the context of a constructivist classroom. On the one hand it could be said that one or other of these features, or the combination of the two, is responsible for the gains, on the other it could be argued that it is not possible to introduce formative assessment without some radical change in classroom pedagogy because, of its nature, it is an essential component of the pedagogic process [p. 9].

Even though formative assessment may be introduced as part of a "radical change in classroom pedagogy," it also creates fundamental changes in teachers' ability to teach effectively. As Darling-Hammond, Ancess, and Falk

(1995) observed in a study of five schools' use of performance assessments to drive high-quality learning, "As [teachers] use assessment and learning dynamically, they increase their capacity to derive deeper understanding of their students' responses; this then serves to structure increased learning opportunities" (p. 131).

CONCLUSION

This section has presented classroom approaches that support sustained inquiry and collaborative work. It is clear that such approaches are critical for preparing students for future learning. The research to date suggests that inquiry-based approaches can be productive and an important way to nurture communication, collaboration, and deep thinking, but it is also challenging to implement them. A major hurdle in implementing these curricula is that they require simultaneous changes in curriculum, instruction, and assessment practices—changes that are often foreign to teachers as well as students (Barron et al., 1998; Blumenfeld, Soloway, Marx, Krajcik, Guzdial, & Palincsar, 1991). Teachers need time—and a community—to support their capacity to organize sustained project work. It takes significant pedagogical sophistication to manage extended projects in classrooms so as to maintain a focus on "doing with understanding" rather than "doing for the sake of doing" (Barron et al., 1998). In the chapters that follow, we examine how meaningful learning that operates from these principles can be pursued in the fields of literacy, mathematics, and science.