A REVIEW OF RESEARCH ON PROJECT-BASED LEARNING

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This review examines research related to a teaching and learning model popularly referred to as "Project-Based Learning" (PBL). All of the research on Project-Based Learning has taken place in the past ten years and most of it in just the last few years. Since there is not a large body of PBL research, the review is inclusive rather than selective.

The review covers eight topics:

- A definition of Project-Based Learning,
- Underpinnings of PBL research and practice,
- Evaluative research: research on the effectiveness of PBL,
- The role of student characteristics in PBL,
- Implementation research: challenges associated with enacting PBL,
- Intervention research: research on improving the effectiveness of PBL,
- Conclusions, and
- Future directions for PBL research.

Defining Features Of Project-Based Learning

Project-based learning (PBL) is a model that organizes learning around projects. According to the definitions found in PBL handbooks for teachers, projects are complex tasks, based on challenging questions or problems, that involve students in design, problem-solving, decision making, or investigative activities; give students the opportunity to work relatively autonomously over extended periods of time; and culminate in realistic products or presentations (Jones, Rasmussen, & Moffitt, 1997; Thomas, Mergendoller, & Michaelson, 1999). Other defining features found in the literature include authentic content, authentic assessment, teacher facilitation but not direction, explicit educational goals, (Moursund, 1999), cooperative learning, reflection, and incorporation of adult skills (Diehl, Grobe, Lopez, & Cabral, 1999). To these features, particular models of PBL add a number of unique features. Definitions of "project-based instruction" include features relating to the use of an authentic ("driving") question, a community of inquiry, and the use of cognitive (technology-based) tools (Krajcik, Blumenfeld, Marx, & Soloway, 1994; Marx, Blumenfeld, Krajcik, Blunk, Crawford, Kelly, & Meyer, 1994); and "Expeditionary Learning" adds features of comprehensive school improvement, community service, and multidisciplinary themes (Expeditionary Learning Outward Bound, 1999a).

This diversity of defining features coupled with the lack of a universally accepted model or theory of Project-Based Learning has resulted in a great variety of PBL research and development activities. This variety presents some problems for a research review. First, as Tretten and Zachariou (1997) report in their observation report on Project-Based Learning in multiple classrooms, the variety of practices under the banner of PBL makes it difficult to assess what is and what is not PBL, and whether what you are observing is a "real project." For example, should a design in which project materials are "packaged" or in which student roles are scripted in advance be considered examples of Project-Based Learning? Are there particular features that must be present or absent in order for an instructional activity to be considered PBL? Second, differences between instances of PBL may outweigh their similarities, making it difficult to construct generalizations, across different PBL models, about such questions as the effectiveness of Project-Based Learning. Third, there are similarities between models referred to as Project-Based Learning and models referred to with other labels, for example, "intentional learning" (Scardamalia & Bereiter, 1991), "design experiments," (Brown,1992) and "problem-based learning' (Gallagher, Stepien, & Rosenthal, 1992). Should these other models be considered part of the PBL literature, and if so, on what basis?

Relatedly, limiting the scope of the review to research articles in which the authors describe their work as Project-Based Learning would seem to leave out prior research into project-focused, experiential education or active learning. After all, the idea of assigning projects to students is not a new one. There is a longstanding tradition in schools for "doing projects," incorporating "hands-on" activities, developing interdisciplinary themes, conducting field trips, and implementing laboratory investigations. Moreover, the device of distinguishing PBL from didactic instruction has its roots in similar distinctions made between traditional classroom instruction and "discovery learning" some twenty years ago.

Yet, there seems to be something uniquely different about much of the recent research and practice in Project-Based Learning. This uniqueness can be seen, for example, in the presentations and exhibits at the annual Autodesk Foundation Conference on Project Based Learning (Autodesk Foundation, 1999) where practitioners discuss issues such as whole school change and new school design based on PBL principles. According to Blumenfeld, Soloway, Marx, Krajcik, Guzdial, and Palincsar (1991), previous attempts at hands-on and discovery learning curricula failed to reach widespread acceptance because developers did not base their programs on "the complex nature of student motivation and knowledge required to engage in cognitively difficult work," nor did they give sufficient attention to students' point of view. Other authors mention authenticity, constructivism, and the importance of learning "new basic skills" in attempting to describe the difference between PBL and prior models that involved projects (Diehl et al., 1999).

To capture the uniqueness of Project-Based Learning and to provide a way of screening out non-examples from this review, the following set of criteria are offered. These criteria do not constitute a definition of PBL, but rather are designed to answer the question, "what must a project have in order to be considered an instance of PBL?"

The five criteria are centrality, driving question, constructive investigations, autonomy, and realism.

PBL projects are central, not peripheral to the curriculum. This criterion has two corollaries. First, according to this defined feature, projects are the curriculum. In PBL, the project is the central teaching strategy; students encounter and learn the central concepts of the discipline via the project. There are instances where project work follows traditional instruction in such a way that the project serves to provide illustrations, examples, additional practice, or practical applications for material taught initially by other means. However, these "application" projects are not considered to be instances of PBL, according to this criterion. Second, the centrality criterion means that projects in which students learn things that are outside the curriculum ("enrichment" projects) are also not examples of PBL, no matter how appealing or engaging.

PBL projects are focused on questions or problems that "drive" students to encounter (and struggle with) the central concepts and principles of a discipline. This criterion is a subtle one. The definition of the project (for students) must "be crafted in order to make a connection between activities and the underlying conceptual knowledge that one might hope to foster." (Barron, Schwartz, Vye, Moore, Petrosino, Zech, Bransford, & The Cognition and Technology Group at Vanderbilt, 1998, p. 274). This is usually done with a "driving question" (Blumenfeld et al., 1991) or an ill-defined problem (Stepien and Gallagher, 1993). PBL projects may be built around thematic units or the intersection of topics from two or more disciplines, but that is not sufficient to define a project. The questions that students pursue, as well as the activities, products, and performances that occupy their time, must be "orchestrated in the service of an important intellectual purpose" (Blumenfeld et al., 1991).

Projects involve students in a constructive investigation. An investigation is a goal-directed process that involves inquiry, knowledge building, and resolution. Investigations may be design, decision-making, problem-finding, problem-solving, discovery, or model-building processes. But, in order to be considered as a PBL project, the central activities of the project must involve the transformation and construction of knowledge (by definition: new understandings, new skills) on the part of students (Bereiter & Scardamalia, 1999). If the central activities of the project represent no difficulty to the student or can be carried out with the application of already-learned information or skills, the project is an exercise, not a PBL

project. This criterion means that straightforward service projects such as planting a garden or cleaning a stream bed are projects, but may not be PBL projects.

Projects are student-driven to some significant degree. PBL projects are not, in the main, teacher-led, scripted, or packaged. Laboratory exercises and instructional booklets are not examples of PBL, even if they are problem-focused and central to the curriculum. PBL projects do not end up at a predetermined outcome or take predetermined paths. PBL projects incorporate a good deal more student autonomy, choice, unsupervised work time, and responsibility than traditional instruction and traditional projects.

Projects are realistic, not school-like. Projects embody characteristics that give them a feeling of authenticity to students. These characteristics can include the topic, the tasks, the roles that students play, the context within which the work of the project is carried out, the collaborators who work with students on the project, the products that are produced, the audience for the project's products, or the criteria by which the products or performances are judged. Gordon (1998) makes the distinction between academic challenges, scenario challenges, and real-life challenges. PBL incorporates real-life challenges where the focus is on authentic (not simulated) problems or questions and where solutions have the potential to be implemented.

Accordingly this review covers research and research-related articles on "project-based learning," "problem-based learning," "expeditionary learning," and "project-based instruction" that conform to the criteria above. The review is focused, primarily, on published research conducted at the elementary and secondary level. In the interest of constructing a concise summary of current research activity, the review does not include attention to similar models of instruction such as "active learning," "contextual learning," "design-based modeling," "collaborative learning, "technology-based education," and "design experiments," although some of the research in these areas is likely to be relevant to PBL.

Underpinnings of Project Based Learning

There are at least three traditions from which PBL research and practice seem to emerge: (1) Outward Bound wilderness expeditions, (2) postsecondary models of "problem-based" learning, and (3) university-based research in cognition and cognitive science applications.

Outward Bound and the Learning Expedition

"Expeditionary Learning" (EL) is a PBL design that grew out of Outward Bound (OB), an adventure and service-based education program known for its wilderness expeditions. EL learning expeditions are defined as "intellectual investigations built around significant projects and performances." These expeditions combine intellectual inquiry, character development, and community building (Udall & Rugen, 1996, p. xi).

Although descriptions of expeditions (Udall & Mednick, 1996) resemble descriptions of projects in the PBL literature, Expeditionary Learning classrooms differ from other Project-Based Learning classrooms in conceptual as well as structural ways. Conceptually, learning expeditions tend to embody some of the characteristics of wilderness expeditions. They invariably involve fieldwork, service, teamwork, character building, reflection, and building a connection to the world outside of the classroom. Additionally, students keep a portfolio of their work, and schools work to develop a "culture of revision" and craftsmanship. Structurally, EL is a framework for whole school improvement. The Expeditionary Learning model is intended to transform curriculum, instruction, assessment, and school organization. Thus, Expeditionary Learning classrooms tend to have a number of unique structural features, including technical assistance links with Expeditionary Learning Outward Bound (ELOB) centers in their region (or with national faculty), logistical arrangements such as flexible or block scheduling and heterogeneous grouping, whole school changes in school organization and culture, and increased involvement of parents and community people (New American Schools Development Corporation, 1997). Among the structural features, perhaps the most unique feature is that participation in Expeditionary Learning tends to alter teaching assignments such that teachers tend to work with the same group of students for two years or longer (Rugen & Hartl, 1994).

Problem-Based Learning: Projects Incorporating Ill-Defined Problems

The original problem-based learning model was developed for use with medical students in Canada (Barrows, 1992). The model was designed to help interns improve their diagnostic skills through working on "ill-structured problems." Medical students are introduced to a diagnostic problem, usually a patient with a complaint or illness. Using a database of information and test data about this patient and guided by a facilitator who plays the role of a coach or Socratic questioner, students are led to construct a diagnosis by generating hypotheses, collecting information relevant to their ideas (e.g., interviewing the patient, reading test data), and evaluating their hypotheses. The process, which has been used in business, architecture, law, and graduate education schools (Savey & Duffy, 1985), combines problem statements, databases, and a tutorial process to help students hone their hypothetico-deductive

thinking skills. Similarly, case-based methods have been used in medical, business, and legal education to help students become proficient at preparing briefs and making presentations (Williams, 1992).

More recently, the "problem-based learning" model has been extended to mathematics, science, and social studies classes at the elementary and secondary level (Stepien & Gallagher, 1993). Much of this research has emanated from the Center for Problem Based Learning at the Illinois Mathematics and Science Academy (IMSA) in Aurora, Illinois where the faculty have developed a one-semester problem-based course entitled Science, Society, and the Future focused on "unresolved science-related social issues." Although the research and development activities related to "problem-based learning" described in this review have a tutorial ingredient not found in the average PBL design, the problem-based learning studies have all of the defining features of PBL (centrality, driving question, constructive investigation, autonomy, and realism). Moreover, this tutorial ingredient is not nearly as structured or scripted as it is in post-secondary models and is similar in form to the scaffolding or "procedural facilitation" interventions described in a subsequent section.

Research on Cognition: Challenge, Choice, Autonomy, Constructivism, and Situated Cognition

There are a number of strands of cognitive research cited in support of classroom research and development activities in Project-Based Learning. These strands can be divided into research on motivation, expertise, contextual factors, and technology. Research on motivation includes research on students' goal orientation and on the effect of different classroom reward systems. All things being equal, students who possess a motivational orientation that focuses on learning and mastery of the subject matter are more apt to exhibit sustained engagement with schoolwork than students whose orientation is to merely perform satisfactorily or complete assigned work (Ames, 1992). Classroom reward systems that discourage public comparability and favor task involvement over ego-involvement and cooperative goal structures over competitive goal structures tend to reduce ego threat on the part of students and encourage a focus on learning and mastery (Ames, 1984). Accordingly, Project Based Learning designs, because of their emphasis on student autonomy, collaborative learning, and assessments based on authentic performances are seen to maximize students' orientation toward learning and mastery. Additionally, Project-Based Learning designers have built in additional features such as variety, challenge, student choice, and non-school-like problems in order to promote students' interest and perceived value (Blumenfeld et al., 1991).

Another strand of research on cognition that has influenced Project-Based Learning designs has been research on experts and novices. This research has not only revealed the

importance of metacognitive and self-regulatory capabilities on the part of experts, but also the absence of planning and self-monitoring skills on the part of inexperienced and young problem solvers (Bereiter & Scardamalia, 1993; Glaser, 1988). Accordingly, the way to insure that young children become proficient at inquiry and problem solving is to simulate the conditions under which experts master subject matter and become proficient at conducting investigations (Blumenfeld et al, 1991). This has also led to recommendations for shifting the major portion of instruction in schools from teacher-directed, teacher-assigned "schoolwork" with its emphasis on comprehension, to student-initiated, goal-driven, independent, "intentional learning" models with an emphasis on knowledge building (Bereiter & Scardamalia, 1987; Scardamalia & Bereiter, 1991).

Research on experts and novices has also given practitioners ideas for enhancing students' ability to benefit from Project-Based Learning, primarily through the introduction of varieties of "scaffolding" (learning aids, models, training strategies) intended to help students become proficient at conducting inquiry activities. "The master-apprentice relationship is used as an analogy for the teaching-learning situation...like masters, teachers should scaffold instruction by breaking down tasks; use modeling, prompting, and coaching to teach strategies for thinking and problem solving; and gradually release responsibility to the learner" (Blumenfeld et al., 1991). For example, "cognitive apprenticeship" (Collins, Brown, & Newman, 1991) is a model for teaching and learning in which students: (a) learn the "crafts" of subject matter areas such as mathematics, writing, and reading in the identical context that they would be expected to use these skills in later life; (b) receive a large amount of practice; (c) learn from experts who would model the skills and then give feedback to students as they practice them; and (d) receive an emphasis on the acquisition of metacognitive skills useful for applying the to-be-learned skills.

The influence of contextual factors on cognition has also engendered a good deal of research and has, according to the citations in PBL research, had an important influence on the authenticity and autonomy elements of Project-Based Learning. According to research on "situated cognition," learning is maximized if the context for learning resembles the real-life context in which the to-be-learned material will be used; learning is minimized if the context in which learning occurs is dissimilar to the context in which the learning will be used (Brown, Collins & Duguid, 1989). Additionally, research on contextual factors has led to the recommendation that, to the extent that it is important for students to be able to apply what they learn to solve problems and make decisions, instruction be carried out in a problem-solving context. Learning that occurs in the context of problem solving is more likely to be retained and applied. Such learning is also seen as being more flexible than the inert knowledge that is acquired as a result of more traditional didactic teaching methods (Boaler, 1998b; Bransford, Sherwood, Hasselbring, Kinzer, & Williams, 1990).

Finally, research on the application of technology to learning and instruction has led, in general, to an interest in using technology as a "cognitive tool" and, in particular, to the incorporation of computer hardware and programs into Project-Based Learning as extensions of and models for student capabilities. In addition, technology has, among its touted benefits, the value of making the knowledge construction process explicit, thereby helping learners to become aware of that process (Brown & Campione, 1996). "Using technology in project-based science makes the environment more authentic to students, because the computer provides access to data and information, expands interaction and collaboration with others via networks, promotes laboratory investigation, and emulates tools experts use to produce artifacts." (Krajcik et al., 1994, pp. 488-489).

Research on Project-Based Learning

Research on Project-Based Learning can take several forms. Research can be undertaken in order to (a) make judgments about the effectiveness of PBL (summative evaluation), (b) assess or describe the degree of success associated with implementation or enactment of Project-Based Learning (formative evaluation), (c) assess the role of student characteristic factors in PBL effectiveness or appropriateness (aptitude-treatment interactions), or (d) test some proposed feature or modification of Project-Based Learning (intervention research).

Evaluative Research: Assessing the Effectiveness of Project-Based Learning

There are many ways of making judgments about the effectiveness of Project-Based Learning. Research on the effectiveness of PBL is divided below into five sections. The first section is devoted to research conducted in Expeditionary Learning Schools where the most popular assessment index consisted of scores on standardized tests of academic achievement. The second section presents research conducted using problem-based learning models where the researchers used a variety of independent measures to assess the effectiveness of their models for developing general problem-solving strategies. The third section is devoted to an evaluation of a problem-based mathematics curriculum using both standardized tests and independent measures of mathematical reasoning. The fourth section presents research focused on gains in specific skills taught in the context of projects, often through the use of independent performance tasks. Finally, the last section presents a number of studies that relied on survey methods and participant self-report to evaluate PBL effectiveness.

Gains in Student Achievement: Research conducted in Expeditionary Learning Schools and Co-nect Schools. Expeditionary Learning Outward Bound (ELOB) and Co-nect schools

were part of the New American Schools Designs study and thus have participated in the most extensive evaluation research of any Project-Based Learning context.

With respect to Expeditionary Learning schools, a report by the New American Schools Development Corp (1997) summarizes some of the findings for the school years 1995 through 1997. These and subsequent findings are summarized in two publications of ELOB (1997; 1999a). Overall, ELOB publications report that nine of ten schools that implemented Expeditionary Learning in 1993 demonstrated significant improvement in students' test scores on standardized tests of academic achievement. According to a study conducted by the RAND corporation (ELOB, 1999a), Expeditionary Learning was the most successful program of the six New American School designs implemented in 1993, and EL schools have continued to deepen their implementation and improve year to year.

The gains exhibited in academic achievement on the part of Expeditionary Learning schools are quite dramatic. In Dubuque, Iowa, three elementary schools implemented the EL program. After two years, two of these schools showed gains on the Iowa Test of Basic Skills from "well below average" to the district average; the third school showed a gain equivalent from "well below average" to "well above the district average." The magnitude of the 1995 to 1997 gains in reading for the three EL schools ranged from 15% in one school to over 90% in the other two schools, while the averages for other schools in the district remained unchanged. After four years of EL implementation, graduates from these three Dubuque EL schools scored "above the district average in almost every area."

In Boston, eighth-grade students at an inner-city, EL school exhibited the second highest scores in the district on the Stanford 9 Open Ended Reading Assessment, scoring behind the exclusive Boston Latin School (ELOB, 1999a). An EL elementary school in this district ranked 11th in mathematics and 17th in reading out of 76 elementary schools on this same test, despite serving a population that is 59% Hispanic and 27% African American (ELOB, 1999b).

Similarly, in Portland, Maine, an EL middle school showed increases for the school year 1995-1996 in all six curriculum areas assessed with the Maine Educational Assessment battery, this in contrast to the previous school year (prior to the onset of EL) and the results of the state as a whole. Again, the improvement scores were of a magnitude three to ten times larger (a 59 point increase, on the average) than that of the state as a whole (average gain of 15 points). Moreover, these improvement scores occurred at a time when the percentage of limited English speaking students increased in this EL middle school from 6% to 22% (ELOB, 1999a), and these gains did not level out but increased an average of 25 additional points the following year (ELOB, 1999b). Similar dramatic gains are reported for schools in Colorado, Decatur, Georgia, Cincinnati, Ohio, Memphis, Tennessee, and New York City. (ELOB, 1999a, 1999b).

As important as these gains in academic achievement have been for validating the EL model, an additional study of EL schools conducted by the Academy for Educational Development (AED) demonstrated some interesting additional effects of EL implementation (ELOB, 1999a, 1999b). Results from classroom observation, teacher interviews, and analyses of teacher reports in ten EL schools revealed that Expeditionary Learning schools influenced school climate and student motivation. According to this report, the Expeditionary Learning experience increased participating teachers' beliefs in their ability to teach students of different ability levels, conduct assessments, and use parents and outside experts in the classroom, as well as their confidence in themselves as teachers and learners. A companion report produced by the University of Colorado found that Expeditionary Learning in Colorado schools "consistently promoted structural changes such as block scheduling, increased partnership with the community, authentic assessment, teaming of teachers, and interdisciplinary project-based curriculum." (ELOB, 1999a). Additionally, the AED report found attendance to be high in all EL schools, with an average attendance rate across all schools of over 90%. For example, according to this report, attendance at a participating elementary school in Cincinnati increased from 75% before the implementation of EL to over 95% after two years of EL. Additionally, the AED report found rates of retention, suspensions, and other indices of disciplinary problems to be unusually low in EL schools.

Similar dramatic gains in academic achievement were reported for Co-nect schools. Co-nect, like Expeditionary Learning, is a comprehensive, whole-school reform effort that places strong emphasis on project-based learning, interdisciplinary studies, and real-world applications of academic content and community service. Co-nect is also characterized as having a central emphasis on technology (Becker, Wong, & Ravitz, 1999). A study conducted by University of Memphis researchers (Ross et al., 1999) compared Co-nect schools to control schools in Memphis on Tennessee's Value-Added Assessment System. According to this report, Co-nect schools gained almost 26% more than the control schools over the two year period 1996-1998 and showed strong achievement gains in all subject matter areas. Comparable gains were reported for Co-nect schools compared to district averages in a separate independent evaluation of Co-nect schools in Cincinnati for the period 1995-1999 (Cincinnati Public Schools, 1999).

It should be noted that the findings reported above are drawn from ELOB and Co-nect publications, respectively. Even if these findings and interpretations are accurate, they were undoubtedly selected for their salience and positive direction. It is quite possible that a full set of findings would reveal schools in which gain scores on standardized achievement tests were minimal or negative. In addition, even if the results selected by ELOB and Co-nect for display in their publications were representative of all schools in all years of the study, these results may

be attributed, in part, to features of these programs other than Project-Based Learning (e.g., portfolios, flexible block scheduling for ELOB; technology in the case of Co-nect schools).

Nevertheless, the magnitude of the gains reported above are impressive for a number of reasons. First, that an instructional intervention of any kind was successful at boosting academic achievement is remarkable in its own right. For the most part, attempts to raise students' scores on standardized achievement tests have not met with great success. Second, there is no particular reason to expect that Expeditionary Learning or Co-nect would have an impact on standardized achievement tests, especially in reading and mathematics. That is, the learning expeditions that form the core of EL and the technology projects that are central to Co-nect do not target the basic skills tapped by standardized achievement tests, at least not directly. Typically, projects target content areas topics or technological operations. Skills of reading, writing, and computation are often involved in constructing project products, but these skills are rarely introduced in the context of projects. Thus, in both of these instances, the reported effects of PBL-based programs on students' basic skills achievement may be the result of a generalized effect associated with the whole school reform effort or, perhaps, the motivational effect of project-based instruction may lead to increased student attendance, attention, and engagement during the (non-project) periods students spend learning basic skills. More research and more in-depth analyses of existing research would seem to be called for.

Gains in Students' Problem Solving Capabilities: Research using a Problem-Based Learning Model of PBL. Faculty of the Illinois Mathematics and Science Academy and the Chicago Academy of Science have collaborated on studies examining the effect of a high-school version of the problem-based learning model on students' academic achievement and problem-solving skills. Gallagher et al. (1992) devised a problem-based course for high-school seniors enrolled in an Illinois school for students talented in mathematics and science. In each semester that the course was given, students were presented with two "ill-structured" problems along with raw data relevant to the problem. For example, information was presented to students about an unusually high number of persons dying of a disease with flu-like symptoms in hospitals across Illinois. Students were assigned specific tasks to (a) determine if a problem existed, (b) create an exact statement of the problem, (c) identify information needed to understand the problem, (d) identify resources to be used to gather information, (e) generate possible solutions, (f) analyze the solution using benefit /cost analysis and ripple-effect diagrams, and (g) write a policy statement supporting a preferred solution. Aside from this list of tasks, the procedure for the course was reported to be relatively non-directional. Students worked autonomously to define and seek a solution to the problem posed for them, investigating leads, asking for additional information, analyzing data, etc. Results from this study focused on performance on a problem-solving test given as both a pretest and posttest. Gains between the pretest and posttest for the

78 students in the experimental group were compared to those for a matched comparison group that did not participate in the problem-based learning course. In the pretest and posttest, students were asked to describe a process for finding a solution to an ill-defined problem situation (unrelated to the problems administered in the course). Their responses were scored using a six "step" or six category checklist. Of the six steps evaluated, only one, "inclusion of problem finding" showed a significant increase between the pretest and posttest for the experimental group.

A subsequent study by Stepien et al. (1993) describes research conducted in two secondary-level settings, an elective science course for seniors and a more traditional course in American Studies for sophomores. In this study, the problem used in the science course was one designed to prompt students' consideration of ethical as well as biological issues. Likewise, the social studies problem combined historical with ethical issues. Students were asked to advise President Truman on how to bring a speedy end to the war based on an unconditional surrender by the Japanese and the assurance of a secure postwar world.

The effectiveness of the two problem-solving courses was evaluated using pretest to posttest gains on a measure of factual content for the tenth-grade course and a measure assessing the breadth of students' ethical appeals for the twelfth-grade course. In the case of the 10th-grade American Studies course, experimental students demonstrated equivalent or better knowledge of factual content as compared to a control class that studied the same period of history, but did not engage in problem solving.

As was the case in the Gallagher et al. (1992) study, students enrolled in the problem-solving course for seniors, along with a matched group of control seniors, were given an ill-structured problem as a pretest and another such problem as a posttest. All students were instructed to outline a procedure they might use to arrive at a resolution to the problem. According to the scoring procedure employed in this study, students who took the problem-solving courses outperformed control students in the breadth of their ethical appeals and in the extent to which they tended to support their appeals with reasoned arguments.

Results on the effectiveness of a more “packaged” approach to problem-based learning are provided in a study by Williams, Hemstreet, Liu, and Smith (1998). In this study, conducted with 117 seventh grade science students, students taking a problem-based learning program presented via CD-ROM outperformed a control group that received more traditional instruction on a measure of knowledge of science concepts.

Additionally, there are several articles in the literature in which the authors report success for the use of a problem-based learning model for other populations and other curriculum domains, albeit without including data. Gallagher, Stepien, Sher, and Workman (1995) report the successful use of the model with fifth-grade students on problems relating to

the ecosystem; Sage (1996) describes the implementation of problem-based learning by science and language arts teams in an elementary and a middle school; Savoie and Hughes (1994) describe a study involving a two-week problem-based (actually, case-based) unit for ninth-grade students focused on family dynamics; Boyce, VanTassel-Baska, Burrus, Sher, and Johnson, 1997) describe a curriculum for high-ability learners in Grades K-8, developed at the College of William and Mary, that presented highly salient, systemic problems for students to investigate (e.g., archeology, pollution, human immunology, ecosystems); and Shepherd (1998) reports on a study conducted with fourth- and fifth-grade students using social studies problems.

The effectiveness of Project- or problem-based learning can be evaluated by looking at the performance of program graduates. Ljung and Blackwell (1996) describe Project OMEGA, a program for at-risk teens that combines traditional instruction with problem-based learning (part of the Illinois Network of Problem Based Learning Educators) that constitutes a school-within-a-school. The authors report positive transfer following enrollment in Project OMEGA. Graduates of the program all passed their English, US history, and mathematics courses in the year following exposure to the program, although the authors fail to provide sufficient information to allow one to evaluate the meaning or significance of this outcome.

Shepherd (1998) reports that problem-based learning can have a positive effect on students' acquisition of critical thinking skills. Shepherd describes a nine-week project in which students work on defining and finding solutions for a problem related to an apparent housing shortage in six countries. Although the number of students involved in the study was quite small (20 students in the experimental group and 15 in a control group), Shepherd found a significant increase on the part of the experimental group, as compared to the control students, on a test of critical thinking skills (The Cornell Critical Thinking Test). Additionally, experimental students reported increased confidence and learning, as a result of the nine-week project, on a self-report measure given after the program.

Gains in Students' Understanding of the Subject Matter: A Longitudinal Study of Two British Secondary Schools. One of the most powerful designs for conducting research on instructional practices involves comparing students' performance on some criterion measure before and after an experimental treatment, while at the same time being able to compare these gains to those of a comparison group that is similar to the experimental group in all respects except the nature of the treatment. Only one study of Project-Based Learning effectiveness was found that incorporates this research design.

Boaler (1997) describes a longitudinal study of mathematics instruction conducted in two British secondary schools. This study was also reported in Education Week (Boaler, 1999) and in Boaler (1998a, 1998b). As mentioned, the study has several features that make it a significant study of Project-Based Learning effectiveness. Most important, the study

employed a closely-matched (though not randomly-assigned) control population. In addition, the study included pre- and post measures, it was a longitudinal study that lasted for three years, thus allowing for multiple measures of growth, and the experimenter included a variety of instruments, throughout the study, to assess students' capabilities, achievement, and attitudes.

The two schools were selected for their differences with respect to traditional versus project-based methods of instruction. One of the schools (referred to here as "traditional") was characterized as incorporating a more teacher-directed, didactic format for instruction. Mathematics was taught using whole class instruction, textbooks, tracking, and the frequent use of tests. At the second school (referred to here as "project-based"), students worked on open-ended projects and in heterogeneous groups. Teachers taught using a variety of methods with little use of textbooks or tests, and they allowed students to work on their own and to exercise a great deal of choice in doing their mathematics lessons. The use of open-ended projects and problems was maintained in the project-based school until January of the third year of the study at which time the school switched to more traditional methods in order to prepare students for a national examination.

The study was conducted by following a cohort of students from each school (300 students in all) for three years as they moved from Year 9 (age 13) to Year 11 (age 16). Boaler observed approximately 90 one-hour lessons in each school, and she interviewed students in the second and third year of the study, administered questionnaires to all students in each year of the study, and interviewed teachers at the beginning and the end of the research period. In addition, she collected documentation, administered assessments, and analyzed student responses to a standardized national assessment measure, the General Certificate of Secondary Education (GCSE).

Students in the two schools were considered to be comparable in background and ability. At the beginning of the research period, students entering the project-based school and the traditional school were similar in socioeconomic status, they had experienced the same approaches to mathematics instruction in prior years, and they showed similar mathematics achievement performance on a range of tests. Results from a national, standardized test of mathematics proficiency administered at the beginning of the first year of the study (students' year 9) revealed no significant differences between the scores of students enrolled in the traditional school and those of students enrolled in the project-based school. The majority of students in both schools scored below the national average for the test, 75 and 77 percent, respectively.

During the three-year period of the study, the author observed and interviewed students periodically. At the traditional school, students' responses to the textbook-based teaching were, according to Boaler, "consistent and fairly unanimous...the majority of students reported

that they found (the) work boring and tedious." Moreover, "the students regard mathematics as a rule-bound subject and they thought that mathematical success rested on being able to remember and use rules." In contrast, students at the project-based school regarded mathematics as a "dynamic, flexible subject that involved exploration and thought." (Boaler, 1997, p. 63).

Results from mathematical assessments administered in each of the three years favored the students at the project-based school. Students at the project-based school performed as well as or better than students at the traditional school on items that required rote knowledge of mathematical concepts, and three times as many students at the project-based school as those in the traditional school attained the highest possible grade on the national examination. Overall, significantly more students at the project-based school passed the national examination administered in year three of the study than traditional school students.

This study is of great value for examining the question of PBL effectiveness because Boaler chose to examine differences in the quality of students' learning between traditional and project-based contexts. Items on the national examination were divided into procedural and conceptual questions. Procedural questions were questions that could be answered by recalling a rule, method, or formula from memory. An example of a procedural question was "calculate the mean of a set of numbers." Conceptual questions were more difficult. Conceptual questions could not be answered using verbatim information learned in the course. These questions required thought and sometimes the creative application and combination of mathematical rules. An example of a conceptual question was to calculate the area of one of four rectangles in a shape made up of four rectangles given only the area for the entire shape.

Students at the project-based school outperformed students at the traditional school on the conceptual questions as well as on a number of applied (conceptual) problems developed and administered by Boaler. According to the author, these results suggest that students at the two schools had developed a different kind of mathematics knowledge. These different forms of knowledge were also reflected in students' attitudes toward their knowledge. Not only were students at the traditional school unable to use their knowledge to solve problems, but according to Boaler, " Students taught with a more traditional, formal, didactic model developed an inert knowledge that they claimed was of no use to them in the real world." In contrast, "Students taught with a more progressive, open, project-based model developed more flexible and useful forms of knowledge and were able to use this knowledge in a range of settings." (Boaler, 1998a).

Gains in Understanding Relating to Specific Skills and Strategies Introduced in the Project: Laboratory Studies of Project-Based Learning Effectiveness. The research presented below is unique in its employment of performance tasks to assess students' acquisition of

specific skills that were the focus of project activities. These studies are probably more closely related to the typical PBL assessment paradigm where a brief project is followed by some exhibition and where students' products or performance associated with this exhibition are used by teachers (or others) to make inferences about what and how much has been learned.

Staff of the Cognition and Technology Group at Vanderbilt University (CTGV) have been developing projects and evaluating students' performance on tasks linked to these projects for the past several years. The CTGV studies have, for the most part, involved video-based stories that introduce complex problems or project ideas. Despite the somewhat "packaged" nature of the projects administered at Vanderbilt and the use of tightly-controlled experimental designs, the CTGV studies are of interest for the question of PBL effectiveness because they incorporate authentic, independent, performance measures administered to assess specific outcomes. For example, in a study reported by Barron et al. (1998), students worked for five weeks on a combination of problem-based and Project-Based Learning activities focused on teaching students how basic principles of geometry relate to architecture and design. The "packaged" or simulated problem-based part of the program (the SMART program) involved helping to design a playground; the subsequent, project-based component was a less structured activity, designing a playhouse that would be built for a local community center. Following experience with the simulated problem, students were asked to create two- and three-dimensional representations of a playhouse of their own design and then to explain features of each in a public presentation to an audience of experts.

Results of the study were presented in terms of three measures of student learning: a design task that assesses how well students handle a new design problem, a measure of students' understanding of standards-based geometry concepts, and a measure of students' collaborative design proficiency. Although the study was conducted without a control group, pretest-posttest comparisons revealed that (a) students in all ability levels showed gains in design proficiency as measured by the ability to use scale and measurement concepts on their blueprints; (b) students in all ability groups made significant gains in their ability to answer traditional test items covering scale, volume, perimeter, area, and other geometry concepts; and (c) of the 37 designs submitted, 84% were judged to be accurate enough to be built, a result that the researchers regard as a high rate of achievement. In addition, follow-up interviews of students and teachers revealed that students took advantage of opportunities to consult available resources and to revise their work --- behaviors that were described as uncharacteristic of these students prior to their PBL work.

An earlier study reported by the Cognition and Technology Group at Vanderbilt (1992) was conducted with over 700 students from eleven school districts, with five of the sites employing matched control groups. Students were given three adventure "projects" over the

course of three weeks (the "Jasper" series: videotaped problems that package all the information required for project work, but allow some autonomous activity), two on trip planning and one on using statistics to create a business plan. The effectiveness of these projects was measured by means of a series of tasks administered after the three-weeks of project work. Results were reported in five areas: basic math concepts, word problems, planning capabilities, attitudes, and teacher feedback. As expected, the largest gains were observed in planning capabilities, word problem performance, and attitudes towards mathematics. Students exposed to the Jasper problems showed positive gains in all areas compared to untreated control students. According to the researchers, the significance of the study was that it demonstrated that a brief Project-Based Learning experience ("anchored instruction," in their terminology) can have a significant impact on students' problem-solving skills, metacognitive strategies, and attitudes towards learning. Results from the attitude surveys were similar to those reported by Boaler (1997): In comparison to the gains made by untreated control students, experience with a project approach to mathematics was associated with a reduction in anxiety toward mathematics, greater willingness to see mathematics as relevant to everyday life, and increased willingness to approach mathematical challenges with a positive attitude.

The CTGV studies are exemplary because of their use of performance tasks that are independent of the project experience itself. Yet, from the point of view of making generalizations to the situation that most practitioners find themselves in, i.e., assessing what students have learned from projects conducted under their own direction, these studies have at least two shortcomings. First, as mentioned, the CTGV studies employ "packaged" projects which allows for the possibility that students' performance on posttest measures is more attributable to the direct instruction and guided inquiry included in the project "package" than it is to more widespread features of Project-Based Learning: student autonomy, authenticity, opportunity to construct meaning. Second, the CTGV studies (like most PBL studies) do not try to assess whether students, in comparison to students taught with other methods, have failed to progress in other realms as a result of time spent with PBL activities.

A study reported by Penuel and Means (2000) incorporates real-world, student-directed projects on the one hand and a combination of project-specific performance tasks and more general ability measures on the other. This study, which was conducted by SRI International, reports on a five-year evaluation of the Challenge 2000 Multimedia Project in California's Silicon Valley. Student participants worked on a variety of projects and then presented their work at regional Multimedia Fairs. In order to assess the effectiveness of these varied experiences, SRI staff gave students an additional project and observed how they went about completing it. Students in both project and comparison classrooms were asked to develop a brochure, targeted at school officials, that would inform people about the problems

faced by homeless students. Students who had taken part in the Multimedia Project outperformed comparison students on all three measures associated with the brochure task: content mastery, sensitivity to the audience, and coherent design (integrating multiple graphical and textual elements). In addition, results from the study demonstrated that gains in these skills were not achieved at the cost of growth in other areas. Students in the Multimedia Project made the same progress as did students in the comparison classes on standardized tests of basic skills.

Perceived Changes in Group Problem Solving, Work Habits, and other PBL Process Behaviors: Effectiveness as Measured by Self-Report Measures. Among the easiest ways to assess the effectiveness of an instructional treatment is to ask participants what they perceived to be its benefits or effects. Questionnaires and interviews are easy to administer and, sometimes, self-report measures are the only reasonable way to measure changes in dispositions, attitudes, and social skills. However, self-report measures are not measures of what happened, but of what participants believe happened, and thus reliance on these measures can be deceiving.

Tretten and Zachariou (1995) conducted an assessment of Project-Based Learning in four elementary schools using teacher questionnaires, teacher interviews, and a survey of parents. Of interest in this study was the fact that the schools involved had only recently begun to experiment with Project-Based Learning and that all teachers, a total of 64 across the four schools, were surveyed. The average percentage of instructional time devoted to Project-Based Learning across all schools and teachers was 37%. According to teachers' self-reports, experience with Project-Based Learning activities had a variety of positive benefits for students including attitudes towards learning, work habits, problem-solving capabilities, and self esteem. In summary, the authors state that:

" Students, working both individually and cooperatively, feel empowered when they use effective work habits and apply critical thinking to solve problems by finding or creating solutions in relevant projects. In this productive work, students learn and/or strengthen their work habits, their critical thinking skills, and their productivity. Throughout this process, students are learning new knowledge, skills and positive attitudes." (p.8)

A follow-up study conducted by Tretten and Zachariou (1997) expanded the survey to include fourteen schools, some of which had been involved with Project-Based Learning for three years. In this study, an attempt was made to validate teachers' self-report ratings from the previous study by observing students working on projects. Unfortunately, the observation framework and scoring system was found to be unwieldy and was abandoned. The teacher surveys, however, did reveal at least one interesting finding. Teachers were asked to indicate the relative frequency with which students exhibit different kinds of learning while working on

projects. The scale used was a four-point scale ranging from a 1 for "none of the time", 2 for "some of the time", 3 for "most of the time", and 4 for "almost all the time". As expected for this kind of abbreviated scale, the average ratings for different kinds of learning outcomes (e.g., "problem-solving skills," "knowledge/content," "responsibility") showed little variance and were relatively high (all averages were between a 3 and a 4, that is, between "most of the time" and "almost all of the time"). Yet, the order of importance of each type of learning was interesting. Highest ratings were given to "problem-solving skills" (3.47) and "aspects of cooperation" (3.47), with all other learning outcomes ranging between 3.32 ("critical thinking skills") and 3.43 ("aspects of responsibility") except one: Teachers gave their lowest rating overall (3.07) to the statement "I believe they learn important knowledge/content." These teachers seem to believe that learning subject matter content is not one of the principal benefits of Project-Based Learning.

Other studies in which self-report data was used as a measure of project effectiveness include an examination of the effect of Project-Based Learning on third-, fifth-, and tenth-grade students identified as low in motivation (Bartscher, Gould, & Nutter, 1995). After taking part in project work, most of these students (82%) agreed that projects helped motivate them, and most (93%) indicated increased interest in the topics involved. This study also included an independent measure of project effectiveness, percentage of homework completion. However, the 7% increase in homework completion attributed to the project work is quite small and, given the lack of a control group in the study, difficult to interpret.

In another study conducted by Peck, Peck, Sentz, and Zasa (1998), high school students participating in a humanities course using a project approach were asked to indicate how much they learned from the course. Results revealed that students perceived that they learned literacy skills from participation in the course such as using multiple texts, revisiting texts, and evaluating information.

All of the studies in this section highlight the weaknesses of self-report data. Exposure to something new (a project approach) may lead participants to report that learning took place when no such effect occurred. The tendency to report positively about an experience is heightened for teachers when students seem unusually engaged and for students when the activity is provocative and fun. Project-Based Learning, because of its unschool-like, engaging features may lead participants to over-estimate its learning benefits. Assessing the effectiveness of Project-Based Learning by means of observation has the same pitfall.

One additional self-report study is interesting for its use of comparison samples and because its survey questions were focused on matters of fact rather than on opinions. Becker et al. (1999) report on the results of a survey given to 21 teachers in six schools that were participating in a whole-school, technology- and project-based reform effort, Co-nect. Survey

results from Co-nect schools were compared to those from schools participating in other reform efforts and from a national probability sample of schools. In comparison to teachers representing other reform efforts, teachers from Co-nect schools indicated greater frequency in their use of computers, varieties of software programs, the internet, small-group work, lengthy projects, in-depth coverage of topics, student-led class discussions, and constructivist student activities such as reflective writing and having students represent ideas in more than one way. Also, in comparison to survey results from other reform efforts, Co-nect teachers indicated that their students engaged less frequently in seatwork, answering questions in class, and answering questions from the textbook. Although these results from the Co-nect schools are probably indicative of successful implementation of the Co-nect program, it is difficult to interpret their meaning beyond that. That is, indications of the frequency of student activity of one kind or another reveal more about the characteristics of the program than they do about that program's effects or effectiveness.

Research on the Role of Student Characteristics in Project-Based Learning

There are a number of ways that research on student characteristics in Project-Based Learning can be conducted. Researchers can be interested in the differential appropriateness or effectiveness of PBL for different kinds of students. Alternatively, researchers can attempt to alter PBL designs or features in order to adapt to (accommodate, remediate) student characteristic variables. There are a number of student characteristic variables that might be investigated in the context of Project-Based Learning. For example, although no research was found to support this hypothesis, several PBL practitioners have stated that PBL, because of its various features, is a more effective means of adapting to students' various learning styles or "multiple intelligences" (Gardner, 1991) than is the traditional instructional model (e.g., Diehl et al., 1999). Other student characteristic variables that could be investigated include age, sex, demographic characteristics, ability, and a host of dispositional and motivational variables.

Only four studies were found that investigated the role of individual differences in Project-Based Learning. Rosenfeld and Rosenfeld (1998) were interested in investigating the learning styles of students who were characterized by their teachers as "pleasant surprises" (students who perform poorly in conventional classrooms, but who do well in PBL activities) and "disappointing surprises" (students who performed well in conventional classrooms, but who turned in poor projects or no projects at all). Eleven students from three eighth-grade science and technology courses were identified as "surprises" by their teachers. According to the performance of these students on the 4-MAT and LCI, two learning styles inventories, students characterized as "pleasant surprises" exhibited high scores on inventory scales for applied, discovery (as measured by the 4-MAT), technical, and/or confluent processing (as measured by

the LCI), whereas students who were characterized as "disappointing surprises" scored high on the fact-oriented scale of the 4-MAT. The authors suggest that students who do poorly in traditional classrooms may have learning styles that are mismatched to the orientation toward the transmission of facts characteristic of these contexts. They suggest further that these students be exposed to PBL contexts where their learning styles constitute a better match.

In another investigation focused on learning styles, Meyer, Turner, and Spencer (1997) divided a group of fifth- and sixth-grade students into "challenge seekers" versus "challenge avoiders" based on surveys and interviews. Meyer et al. hypothesized that "challenge seekers" who have a higher tolerance for failure, a learning (vs. performance-focused) goal orientation, and higher than average self-efficacy in math would approach Project-Based Learning with greater interest and mastery focus than would "challenge avoiders." Although there were some indications that individual differences in students' motivation patterns relate to differences in PBL behavior (e.g., tolerance for error, persistence, flexibility), the small sample in this study reduced the study to an exploratory investigation.

Horan, Lavaroni, and Beldon (1996) observed Project-Based Learning classrooms at two time periods during the year, once in the fall and once in the spring semester. At both occasions, they compared the behavior of high ability to low ability PBL students in group problem-solving activities. Observers looked at five critical thinking behaviors (synthesizing, forecasting, producing, evaluating, and reflecting) and five social participation behaviors (working together, initiating, managing, inter-group awareness, and inter-group initiating). Results from the study are provocative, but difficult to assess. Overall, high-ability students engaged in the criterion social participation behaviors more than two and one-half times as frequently as low-ability students in the four classes observed and engaged in critical thinking behaviors almost 50% more frequently. The interesting finding, however, was that lower ability students demonstrated the greatest gain in critical thinking and social participation behaviors, an increase of 446% between the fall and spring observation, compared to an increase of 76% for the high-ability students.

Finally, Boaler (1997), in her investigation of mathematics learning in two contrasting schools, found differences between girls and boys in their preferred mode of learning and in the extent to which they could adapt to different forms of instruction. Girls were found to be more disaffected by traditional instruction than boys and showed lower achievement than a matched sample of girls taught with project-based methods. Boaler suggests that girls seem to prefer being taught using methods that stress understanding vs. memorization and learning procedures. Boaler suggests further that exposure to project-based methods might raise the mathematical achievement of all students, especially girls.

There is a frequently voiced claim that Project-Based Learning is an effective method for prompting heretofore reluctant and disengaged students (e.g., low-achieving students) to become motivated and engaged learners (Jones et al., 1997). Unfortunately, no studies were found in which this claim was investigated.

Implementation Research: Challenges Associated with Enacting PBL

Implementation research consists of studies designed to describe and inform the processes of planning and enactment of Project-Based Learning. Typically, implementation research involves observation, questionnaires, and interviews intended to identify difficulties encountered by participants with different aspects of the planning or enactment process. Implementation research is also referred to as formative evaluation and can be focused on a variety of participants (e.g., teachers, students, administrators, parents), factors (e.g., classroom factors, external factors, supports), and contexts (e.g., planning, working with others, enacting, troubleshooting, assessing).

Challenges Encountered by Students. Krajcik, Blumenfeld, Marx, Bass, Fredricks, and Soloway (1998) describe case studies of eight students enrolled in two seventh-grade science classrooms. The case studies were constructed by two classroom teachers during a seven-month period that included a two-month introductory project, a week of training on working together and sharing information, and two subsequent projects, one entitled, "Where does our garbage go?," and the other, "Water, water everywhere! Is there enough to drink?" Students, two boys and two girls in each of the two classes, were selected as representative of the lower middle range of science achievement and on the basis of the likelihood that they would be informative interviewees.

Classrooms were videotaped and students were interviewed frequently. Cases were constructed for each student for each project using videotaped observations, artifacts from the projects, and interview results. Summaries were developed for how each student participated in each aspect of the inquiry: (a) generating questions, (b) designing investigations and planning procedures, (c) constructing apparatus and carrying out investigations, (d) analyzing data and drawing conclusions, and (e) presenting artifacts. Special attention in these summaries was given to "thoughtfulness, motivation, and how group conversation and teacher supports and feedback influenced inquiry."

Results were described with respect to aspects of the inquiry process that students handled adequately and those with which students had difficulty. Students showed proficiency at generating plans and carrying out procedures. However, students had difficulty (a) generating meaningful scientific questions, (b) managing complexity and time, (c) transforming data, and (d) developing a logical argument to support claims. More specifically, students tended to pursue

questions without examining the merits of the question, they tended to pursue questions that were based on personal preference rather than questions that were warranted by the scientific content of the project, they had difficulty understanding the concept of controlled environments, they created research designs that were inadequate given their research questions, they developed incomplete plans for data collection, they often failed to carry out their plans systematically, they tended to present data and state conclusions without describing the link between the two, and they often did not use all of their data in drawing conclusions.

The findings point to the need for developing multiple supports for students as they conduct their inquiry. According to the authors, "We need to consider a range of scaffolds from teachers, peers, and technology that can aid students in examining the scientific worth of their questions, the merits of their designs and data collection plans, the adequacy and systematicity of their conduct of the investigation, and the accuracy of their data analysis and conclusions." (p. 348).

Similarly, Edelson, Gordon, and Pea (1999) report challenges associated with secondary students' ability to conduct systematic inquiry activities in high school science. One challenge is sustaining motivation for inquiry. Students often failed to participate or participated in a disengaged manner. Second, students were sometimes not able to access the technology necessary to conduct the investigation; i.e., they were not able to do the work. Third, students often lacked background knowledge necessary to make sense of the inquiry. Fourth, students were often unable to manage extended inquiry activities

Another study by Achilles and Hoover (1996) reported poor implementation results for three middle schools and one high school classroom taking part in problem-based learning. Students failed to work together well, especially in small groups. The authors attribute these problems to students' lack of social skills. It is difficult, however, to evaluate the meaning of this study. A minimum of data is presented and, more important perhaps, the design of the project consisted of a highly scripted, problem-solving activity which may have accounted for students' desultory participation.

Challenges Encountered by Teachers. Krajcik et al. (1994) describe a four-year University of Michigan research study designed to gather data from teachers who were in the process of implementing Project-Based Science (published projects, in the form of a curriculum, developed at the Technical Education Research Center in Cambridge, MA) in their middle school (four teachers) and elementary school (one teacher) classrooms. All participating teachers attempted to implement the same 6-8 week projects developed by the National Geographic Kids Network. Data sources for the study included audiotapes and videotapes of science lessons, interviews with teachers, and informal conversations. Researchers constructed case reports which focused on the challenges and dilemmas teachers faced as they attempted to

enact features of Project-Based Science. It should be noted that the study involved teachers' attempts to learn and implement an established PBL curriculum, complete with project descriptions, directions for activities, and instructional materials. This implementation situation may be qualitatively different from one in which a teacher decides to plan, develop, and implement a PBL activity on his/her own.

Ladewski, Krajcik, and Harvey (1991) report on one aspect of this University of Michigan study. They describe one middle-school teacher's attempts to understand and enact Project-Based Science. The results from this case study demonstrate how new instructional approaches can conflict with deep-seated beliefs on the part of a teacher, leading to conflicts which can take a good deal of time to resolve. Among the dilemmas that seemed to interfere with a straightforward implementation of PBL in this study are the following: (a) Should time be most effectively used to allow students to pursue their own investigations or to cover the state-prescribed curriculum? (b) Should activities be designed to allow students to seek their own answers or be teacher-controlled so that (all) students obtain the same "correct" results? (c) Should students be given the responsibility for guiding their own learning or should the (more knowledgeable) teacher take responsibility for directing activities and disseminating information in the classroom?

In a companion paper to the papers cited above (Marx, Blumenfeld, Krajcik, Blunk, Crawford, Kelly, & Meyer, 1991) and in a more recent summary of their research, (Marx, Blumenfeld, Krajcik, & Soloway, 1997) the University of Michigan research team describes the common problems faced by teachers as they attempt to enact problem-based science. Marx et al. (1991) summarized their findings under three headings: challenges, enactment, and change. Challenges grew out of difficulties teachers had in accepting the ideas that (a) effective collaboration among students requires more than involvement, it requires exchanging ideas and negotiating meaning; (b) effective use of technology requires that technology be used as a cognitive tool, not merely as an instructional aid; and (c) effective Project-Based Science requires not that all the concepts and facts of the curriculum are covered, but that students construct their own understanding by pursuing a driving question.

Marx et al. (1997) delineate teachers' enactment problems as follows:

> *Time*. Projects often take longer than anticipated. In addition, difficulties that teachers experience in incorporating Project-Based Science into district guidelines are exacerbated by the time necessary to implement in-depth approaches such as Project-Based Learning.
>
> *Classroom management*. In order for students to work productively, teachers must balance the need to allow students to work on their own with the need to maintain order.

Control. Teachers often feel the need to control the flow of information while at the same time believing that students' understanding requires that they build their own understanding.

Support of student learning. Teachers have difficulty scaffolding students' activities, sometimes giving them too much independence or too little modeling and feedback.

Technology use. Teachers have difficulty incorporating technology into the classroom, especially as a cognitive tool.

Assessment. Teachers have difficulty designing assessments that require students to demonstrate their understanding.

Finally, the researchers concluded that change in teachers' learning and behavior tends to take certain forms (Marx et al., 1991, 1997). Teachers prefer to explore those aspects of Project-Based Science related to their professional needs and current capabilities (e.g., technology). Teachers' efforts to change their teaching strategies tend to focus on one or two aspects of the new approach (only) and one or two new strategies designed to cope with new challenges. Teachers tend to modify their practices in idiosyncratic ways, mapping new behaviors onto old behaviors and moving back and forth between old and new practices, sometimes successfully, sometimes not so successfully. In addition, modifying their practices causes teachers to become novices again, which often results in awkward classroom management behaviors and shortcomings associated with orchestrating the multiple features of problem-based science. The authors conclude, however, that problems with enactment can be effectively facilitated by a supportive school environment that allows teachers to reflect on their practices and to attempt changes in these practices through enactment linked with collaboration and feedback.

An additional enactment issue is raised in a study conducted with 27 middle-school science and technology teachers in four schools in Israel (Rosenfeld, Scherz, Breiner, & Carmeli, 1998). In this study, teachers participated in a three-year, in-service program designed to help them develop their students' Project-Based Learning skills and integrate curricular content with these skills. As was observed in the University of Michigan study, the Israeli teachers had a difficult time orchestrating PBL elements, in this case, skill development and curriculum integration. According to Rosenfeld et al. (1998), teachers experienced high "cognitive load" and uncertainty during the course of the in-service which led them to emphasize PBL skill development over curriculum content, leading, in turn, to the development of superficial student projects.

Sage (1996), in reporting on a descriptive research study of elementary and middle school classes in science and language arts, identifies several design challenges associated with

teachers' use of problem-based learning that may well be generalizable to non-problem-focused projects. Chief among the design problems identified by Sage are the difficulties of developing problem scenarios, the tendency for problem scenarios to be structured in such a way that they limit students' inquiry, the difficulty of aligning problem scenarios with curriculum guidelines, the time-consuming nature of developing problem scenarios, and the dilemma associated with using authentic problems --- the more authentic the problem, the more limited students' power and authority to impact a solution. Sage also reports on enactment problems including difficulties in finding the time to implement problems and in facilitating multiple student groups when those groups have students of varying abilities.

Finally, Thomas and Mergendoller (2000) conducted a survey of PBL teachers designed to elicit or construct principles (conditions and strategies) associated with successful implementation of project work. Twelve middle- and high school teachers were selected for their status as expert practitioners in the eyes of their peers. A semi-structured telephone interview schedule was developed in order to elicit considerations and strategies associated with these teachers' planning and enactment activities. The interview consisted of 43 questions relating to such topics as recordkeeping, use of technology, classroom management, and grading. Teachers' responses were then categorized into recurring, qualitatively distinct themes. In the end, teachers' responses were organized into 10 themes. Themes were constructed to reflect the larger issues that seemed to recur across teachers' answers to the interview questions. Principles were summaries of teachers' strategic responses to the issues raised in the themes. An example of a theme was "creating a positive learning environment." Principles associated with this theme were: (1) Establish a culture that stresses student self-management and self-direction; (2) Use models or exemplars of excellent work; and (3) Create a physical environment that will facilitate project work.

Challenges associated with school factors. School factors that facilitate or impede the successful implementation of PBL in classrooms is a popular topic among PBL teachers in schools. It is not as popular as a research focus, possibly because of the difficulty associated with conducting this kind of research. Edelson et al. (1999) describe a number of practical constraints associated with the organization of schools that interfere with successful inquiry. These factors include fixed and inadequate resources, inflexible schedules, and incompatible technology. To this list, Blumenfeld, Krajcik, Marx, & Soloway (1994) add class size and composition, and district curricular policy as restrictions that interfered with enactment of Project-Based Learning. School factors were the prime impediment reported by Hertzog (1994) in a summary of how well Project-Based Learning was operationalized in an elementary school setting. According to Hertzog, the physical organization of the school, limitations on time available for learning, and the perceived need on the part of teachers to structure time in order

to cover all academic subjects tend to interfere with the effectiveness of Project-Based Learning for integrating subject matter areas and providing for in-depth learning.

Intervention Research: Improving the Effectiveness of PBL

An additional strand of research on Project-Based Learning involves attempts to improve the delivery or effectiveness of Project-Based Learning by intervening in the practice of PBL. The intervention may be designed to correct an observed weakness associated with some PBL feature or to remediate or accommodate some student deficiency relative to an aspect of project work. These interventions, which are designed to support Project-Based Learning, have been referred to as scaffolding (Guzdial, 1998) or "procedural facilitation" (Scardamalia, Bereiter, McLean, Swallow, & Woodruff, 1989).

One of the weaknesses of Project-Based Learning, as identified in research on PBL implementation, is that there is often a poor fit between the activities that form the day-to-day tasks of the project and the underlying subject matter concepts that gave rise to the project (Blumenfeld et al., 1991). Projects sometimes go off track, with teachers and students pursuing questions that are peripheral to the subject matter of interest. The solution, according to Blumenfeld et al. (1991) and Barron et al. (1998) is to find ways for projects to center on "learning appropriate goals." For Blumenfeld et al., an appropriate strategy is to help teachers develop "driving questions," questions that will ensure that students encounter and struggle with complex concepts and principles.

Barron et al. take the position that learning appropriate goals can be maintained by introducing explicit design requirements within the problem or project that prompt students to generate and pursue productive questions. Barron et al. describe an intervention research study conducted by Petrosino (1998) in which an enhanced project on the subject of rocketry was compared to a more traditional rocket project. In both projects, students were encouraged to build and launch rockets. In the traditional project, students were called upon to build, launch, and test a rocket. In the enhanced project, students were asked to submit design plans to the National Aeronautics and Space Administration to match a set of design specifications. These specifications called for the "designers" to propose and conduct rocketry experimentation on the relative influence of paint features, external fins, and type of nose cone on the attained height of the rocket launch. Because of this added requirement, students in the enhanced condition ended up learning more about rocketry and controlled experimentation than students in the traditional condition.

Table 1 presents a range of interventions found in the literature. These interventions can be addressed to a variety of student deficiencies or PBL design problems. Table 1 lists interventions addressed to student deficiencies in motivation, asking questions, using

technological tools, and monitoring knowledge, to name a few. Interventions are various as well, including the incorporation of video presentations, models for guiding operations, alterations in goal structure, computer databases, embedded coaching, group process methods, self- and peer-assessment techniques, and opportunities to present to external audiences. It should be noted that the entries in Table 1 are by no means the only interventions described in the broader literature on PBL; they are merely a collection of strategies that are the focus of experimentation in this literature.

Table 1: Interventions Designed to Improve the Effectiveness of Project-Based Learning

CONTEXT	UNDERLYING DEFICIENCY	INTERVENTION	
1. Overall Climate	Students are more engaged and learn more when they are working in a meaningful, non-school-like context.	Using "Generative Learning Environments": Video-based stories that provide a narrative context for problem- and project-based learning (e.g., "Jasper").	Cognitive and Technology Group (1991), Vanderbilt University
	Students are more engaged in school-work when they hold mastery (vs. work completion) goals.	Emphasizing learning vs. work completion and understanding vs. product quality as goals for student work.	Blumenfeld, Puro & Mergendoller (1992); Meyer, Turner, and Spencer (1997)
2. Beginning Inquiry * asking questions * formulating goals * planning procedures *designing investigations	Students have difficulty generating the kinds of essential questions that will lead them to encounter and understand the central concepts of a subject matter area.	Prompting "Learning Appropriate Goals" by introducing specifications, asking for design plans, helping students to develop "driving questions."	Barron et al., (1998)
	Students have difficulty, in general, framing questions to guide their inquiry and, in particular, developing questions that have scientific merit.	Developing a “Computer Supported Intentional Learning Environment:" a student-constructed, collective database (CSILE) in order to make knowledge construction activities overt. Incorporating “cognitive coaching,” e.g., the use of steps to guide beginning inquiry, with peer or teacher feedback.	Scardamalia and Bereiter (1991); Scardamalia, Bereiter, McLearn, Swallow, & Woodruff (1989); Sage (1996)
3. Directing Inquiry * conducting data collection * conducting knowledge searches * constructing knowledge	Students have difficulty with open-ended situations and with ill-defined problems	Providing students with practice in conducting (packaged) problem-based learning activities prior to introducing project-based learning. Providing a structured set of inquiry steps for students to follow.	Barron et al. (1998) Torp and Sage (1998)

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Table 1: Interventions Designed to Improve the Effectiveness of Project-Based Learning (continued)

CONTEXT	UNDERLYING DEFICIENCY	INTERVENTION	SOURCE
3. Directing Inquiry	Students have difficulty with the process of inquiry: They elect to follow dubious, unproductive paths; they have trouble interpreting the meaning of uncovered information; they don't always focus on end goals.	Providing an embedded coaching process that depends on and preserves student initiative, yet allows for teacher interpretation and teacher-student negotiation: "Transformative Communication."	Polman and Pea (1997)
		Embedding guidance for or models of how to conduct an operation within the project materials.	Barron et al. (1998)
4. Analyzing Data and Drawing Conclusions	Students tend to be inefficient when working with technology; they have trouble with time management, they don't break tasks into parts, they don't "debug" their work.	Incorporating a technical assistance model to guide computer work.	Guzdial (1998)
* using formal analytical Methods * using technological Tools			
* keeping on track when using technology	Students have difficulty constructing mental models to guide problem-solving episodes.	Providing on-line assistance ("Toolbox") to help students learn technical skills and computer programs to help them visualize and construct ideas.	Cognitive and Technology Group (1991) Vanderbilt University
6. Collaborating With Others	Students are used to working with others, but not with collaborating, giving feedback, articulating and synthesizing one's work with that of others.	Incorporating a computer mediated "cognitive apprenticeship" model. "Collaborative and multimedia interactive learning environment" (CaMILE).	Guzdial (1998) Hmelo, Guzdial and Toms (1998)
* giving and getting Feedback * collaborating on written work			
* distributing work Equitably	Students often fail to distribute work equitably on their own; thus expertise ends up divided inequitably.	Providing norms for individual accountability.	Barron et al. (1998)
		Incorporating the "jigsaw" method and reciprocal teaching.	Brown (1992)

Table 1: Interventions Designed to Improve the Effectiveness of Project-Based Learning (continued)

CONTEXT	UNDERLYING DEFICIENCY	INTERVENTION	SOURCE
5. Acquiring and Presenting Knowledge * knowing when you Understand * knowing what it means to be an expert * monitoring what is Known * demonstrating the full range of one's competence	Students have difficulty knowing when they comprehend fully. Students have difficulty recognizing gaps in knowledge and knowing where they are in knowledge acquisition activities.	Intervening to require explanations and justifications from students at different stages of the project. Making knowledge building overt, public, and collective (e.g., via computers.) Emphasizing learning vs. work completion and understanding vs. product quality goals for student work.	Blumenfeld, et al. (1992) Scardamalia et al. (1989) Edelson et al. (1999) Blumenfeld, et al. (1992)
	Teachers have difficulty monitoring what is being learned and deciding if and when to provide instruction.	Incorporating "formative self-assessments;" creating a classroom culture that supports frequent feedback and assessment; finding ways for students to compare their work with others. Giving students explicit responsibility for teaching; providing training in "reciprocal teaching."	Barron et al. (1998) Berger (1996) Brown and Campione (1996)
	Knowledge acquisition is often unevenly distributed in PBL.	Providing a method whereby student groups become experts on different topics, then are regrouped to share their knowledge with others: "Jigsaw Method."	Brown (1992)
	Knowledge is often limited by the context within which the learning takes place.	Developing "transfer problems" to administer for practice (or assessment) following each PBL activity.	Barron et al. (1998)
	Students sometimes do not take their PBL work very seriously; they do superficial work and rarely revise their products.	Incorporating presentation opportunities that involve external audiences. Requiring multiple criterion performances (e.g., collaboration, explanation, demonstration, self-report).	Barron et al. (1998) Klein et al. (1997)

An example of an intervention designed to facilitate students' inquiry behavior is "transformative communication" (Polman & Pea, 1997). The authors, in an article described as "interpretive research," point out that Project-Based Learning is often implemented in such a way that students end up engaging in desultory, "unguided discovery." To counter this tendency, it is unsatisfactory to have a teacher intervene and direct students in their inquiry, while it is equally unsatisfactory to allow students to flounder or to put in large blocks of time exploring unproductive ideas in their investigations.

Their solution is to provide a method of coaching that allows students to retain control over their project work. Students make a decision about a path to take. If necessary, the teacher reinterprets the students' move and together the teacher and student reach mutual insights by discussing the implications of the move and making additional suggestions. For example, students proposed an investigation about whether UFOs are alien spaceships. Following an intervention by the teacher, the goal of the investigation was changed to that of confirming or falsifying natural explanations of UFOs. This change preserved the original student interest while changing the topic into one that has scientific merit.

An additional example of an intervention is provided in a study by Moore, Sherwood, Bateman, Bransford, and Goldman (1996). The study was conducted with sixth-grade students and was intended to assess the benefit on Project-Based Learning performance of a prior problem-based learning program. Both experimental and control students were challenged to design a business plan for a booth at a school carnival. Whereas the control group began with this activity, the experimental group was given a three-hour, simulated, problem-based, business planning activity just prior to beginning the project. The resultant business plans developed by experimental and control students at the end of the project period were rank ordered blindly, by judges. Results revealed that the plans developed by experimental students were of a much higher quality than those developed by control students. Closer evaluation of the plans revealed that experimental students' plans incorporated significantly more mathematical methods into each phase of the plan than was the case for control students. Thus, the authors advocate administering content-linked problem-based learning activities prior to implementing PBL activities.

Conclusions

The research reported above includes a variety of investigations and several important findings. Chief among the findings that might be of interest to practitioners are those reported by Boaler (1997) on the effects of PBL on the quality of students' subject matter knowledge, by University of Michigan researchers and others (e.g., Marx et al., 1997) on the challenges faced by teachers and students during PBL implementation, and by the Cognitive and Technology Group of Vanderbilt and others (e.g., Barron et al., 1998) on the effects of "procedural facilitation" interventions on students' skill acquisition in PBL.

Given the current state of research on Project-Based Learning, what can we conclude about the relative merits of PBL as a teaching and learning method? Keeping in mind that the research to date is fairly sparse in each of the paradigms that have emerged and that this research does not reflect a common model of Project-Based Learning, the following tentative conclusions can be offered.

• Research on PBL implementation is largely limited to research on project-based science administered by teachers with limited prior experience with PBL. From this research, there is evidence that PBL is relatively challenging to plan and enact. Keeping the limitations of this research in mind, it is probably fair to say that most teachers will find aspects of PBL planning, management, or assessment fairly challenging and will benefit from a supportive context for PBL administration.

• There is some evidence that students have difficulties benefiting from self-directed situations, especially in complex projects. Chief among these difficulties are those associated with initiating inquiry, directing investigations, managing time, and using technology productively. The effectiveness of PBL as an instructional method may depend, to a greater extent than we recognize, on the incorporation of a range of supports to help students learn how to learn.

• There is direct and indirect evidence, both from students and teachers, that PBL is a more popular method of instruction than traditional methods. Additionally, students and teachers both believe that PBL is beneficial and effective as an instructional method.

• Some studies of PBL report unintended and seemingly beneficial consequences associated with PBL experiences. Among these consequences are enhanced professionalism and collaboration on the part of teachers and increased attendance, self-reliance, and improved attitudes towards learning on the part of students.

• PBL seems to be equivalent or slightly better than other models of instruction for producing gains in general academic achievement and for developing lower-level cognitive skills in traditional subject matter areas.

• More important, there is some evidence that PBL, in comparison to other instructional methods, has value for enhancing the quality of students' learning in subject matter areas, leading to the tentative claim that learning higher-level cognitive skills via PBL is associated with increased capability on the part of students for applying those learnings in novel, problem-solving contexts.

• There is ample evidence that PBL is an effective method for teaching students complex processes and procedures such as planning, communicating, problem solving, and decision making, although the studies that demonstrate these findings do not include comparison groups taught by competing methods.

• Finally, there is some evidence, albeit indirect, that the effectiveness of PBL is enhanced when it is incorporated into whole-school change efforts.

Directions for Future Research

Research on PBL has not had a substantial influence on PBL practice. There are a number of reasons for this pattern. First, this research is very recent. The great majority of research reported above has been conducted in the last few years. Even teachers who have recently entered the teaching profession have probably not been exposed to research on PBL, nor would they be expected to have taken courses in the theory and practice of PBL. Second, the research is not readily accessible to teachers or administrators. PBL research, for the most part, has not been presented or even referred to in popular periodicals or in books. Third, there is not a widely accepted framework or theory of PBL upon which professional development might be based. Fourth, much of the research reported above may be irrelevant to the concerns of classroom teachers. Aside from the evaluation studies of Expeditionary Learning, most of the research on PBL emanates from one of three research centers (University of Michigan, Vanderbilt University, and the Illinois Mathematics and Science Academy). This research tends to focus on "packaged" projects, problems, or curricula rather than on teacher-initiated projects or problems. Most practitioners, however, develop their own projects, either on their own or in collaboration with colleagues on site. This teacher-initiated, "grassroots" model for PBL may well be different from those depicted in existing research in subtle but important ways.

The disconnection between PBL research and practice is more than just unfortunate. Whereas practitioners in traditional classrooms have access to texts, tests, and other materials, as well as to research-based theories and practices associated with designing lessons, developing materials, presenting content, guiding practice, managing classrooms, and preparing tests, PBL practitioners are in a position of having to construct a unique instructional model almost completely on their own without guidance, texts, resource materials, or support. Lacking

information on what PBL practices are most productive, evidence of PBL's relative effectiveness in comparison to other methods, and an overall framework to guide their planning and collaborations, PBL practitioners can be caught in a vulnerable position, unable to justify their practices to critics or to sustain their work long enough to master their craft.

What seems to be needed is nothing short of a new theory of learning and instruction, a theory that will provide, on the one hand, principles for guiding authentic inquiry, knowledge construction (vs. transmission), and autonomous learning for students, and, on the other hand, models for designing efficient and productive (standards-based) projects, shifting responsibility to the learner, coaching without directing, and conducting performance-based assessment for teachers. At the minimum, we need the following kinds of research (see Blumenfeld et al., 1991, for other suggestions):

1. Evidence of the effectiveness of PBL in comparison to other methods. There is a need for more research documenting the effects and effectiveness of PBL. This research is needed not only to guide PBL instruction and the development of projects, but also to provide justification, to the extent merited, for the dissemination and diffusion of PBL practices within and across schools. Included in this research should be experimental comparisons among models of PBL and between these models and critical competitors such as traditional, didactic instruction. Among the questions of interest that might be explored in this research are:

a. What are the tradeoffs associated with depth vs. breadth in evaluations of PBL effectiveness? For example, what are both the costs (e.g., opportunity costs) and the benefits of a six-week PBL experience, in terms of the quality and amount of knowledge gained, in comparison to students taught with a traditional model?

b. How reliable and widespread are the reported positive effects of PBL on students' standardized achievement test scores and under what conditions are they maximized and sustained?

c. What are the effects of PBL on domains other than subject-matter knowledge and under what conditions are these effects maximized? These other domains, which are sometimes referred to as "life skills" or "process skills" include metacognitive skills, social skills, group process skills, multiple intelligences, and dispositions and attitudes associated with independent learning.

d. What are the effects of PBL on students' learning, achievement, dispositions, and attitudes in the months and years following PBL experiences and in other contexts? What are the unanticipated outcomes of PBL experience?

e. What are the differential benefits of PBL for students of different age groups and what are the variations in design features that must be in place in order to achieve maximum benefit for these age groups?

f. What constitutes meaningful evidence of PBL effectiveness in disciplines (e.g., social studies, literature) within which students' demonstration of proficiency is less straightforward than it is in laboratory science and mathematics?

g. What are the benefits of PBL for engaging and fostering the achievement of low-achieving students and for reducing the gap in achievement levels between socioeconomic groups? How effective and acceptable is PBL as a method of instruction for gifted students?

2. Increased research attention on examining the breadth of PBL effects. With a few exceptions, much of the research reported above incorporates only one or two indices of learning to measure PBL effectiveness, typically, academic achievement and conceptual understanding. Elsewhere, observers of some of the newer constructivist models of learning have proposed that evaluations of student learning be conducted using multiple indices, supplementing measures of understanding (application, explanation, concept mapping) with those of collaboration, metacognitive capability, communication, and problem solving (Klein, O'Neil, Dennis, & Baker, 1997). Evaluations of project effectiveness and assessments of student learning might include multiple measures as well: observation, paper and pencil tests, performance tasks, standardized tests, ratings of student products, student self-reports, and the testimony of experts. Additionally, these measures might include attention to varieties of effects: (a) Have students attained the learning goal(s) that gave rise to the project? (b) Can students use what they've learned in other contexts (i.e., transfer of training)? (c) What other skills, strategies, and dispositions (planned and unplanned) have students learned as a result of project work? (d) How has the classroom "culture" changed as a result of project work? and (e) How has project work resulted in changes in individual learners as observed in contexts other than the project classroom?

3. Research on best practices: Procedures for planning, implementing, and managing PBL that are associated with student learning and achievement. There are at least two strands to this research. In the first strand, research on "procedural facilitation" interventions, of the kind listed in Table 1, should be conducted in order to determine the PBL features, materials, requirements, technologies, and assessment strategies that are associated with productive inquiry and maximum achievement on the part of students. Additionally, systematic research should be conducted to determine combinations of these procedural devices that work best for different audiences, purposes, and contexts. A second strand of research might be useful as well. This strand would focus on collecting data on the nature and effectiveness of "grassroots" interventions: interventions that have been designed and implemented successfully by teachers in the field. Personal experience observing PBL in classrooms across the country suggests that teachers are quite aware of student deficiencies and weaknesses in PBL practices and are quite ingenious in developing interventions. An example

of a grassroots intervention is described in a monograph by Berger (1996). Berger describes how students' PBL performance improved as a result of implementing a "culture of quality" in the classroom and school. Features of this culture include an emphasis on student revision, projects with multiple checkpoints, high expectations for student work, use of outside experts, regular critique sessions, and student exhibitions.

4. Research on implementation challenges extended to instances of teacher-initiated PBL. Very little is known about the challenges experienced by teachers in developing and enacting PBL on their own. Existing research on implementation challenges is useful for identifying the kinds of training and support teachers need when using packaged or published materials, but these findings may not generalize to or fully capture the challenges of teacher-initiated PBL.

5. Research on the institutionalization of PBL and on PBL-based whole school change. PBL in practice takes place in the context of a school, a district, and a community. It is important to describe factors that influence the conditions under which PBL thrives and spreads in a school setting and becomes a viable part of the district and community. Thus, the research focus should extend beyond the classroom to those school, district, and community factors that facilitate the institutionalization of PBL at a site, and to the ingredients by which PBL becomes a spearhead for whole school change.

No matter what the educational topic, there is always need for more research. In the case of Project-Based Learning, the lack of an overarching theory or model of PBL, the paucity of research devoted to PBL methods, and the gaps in our knowledge about the relative effectiveness of teacher-initiated projects create an unusual and vulnerable situation for PBL practitioners. The Project-Based Learning movement is growing rapidly and has many strong supporters. Yet the movement is taking place at a time when a much larger and more vocal contingent is pressing, quite successfully, for more emphasis on standardized testing, statewide standards, and increased accountability on the part of teachers and schools, all emphases that tend to move schools in the direction of traditional, teacher-directed instruction. Thus, there is a timely need for expansion of some of the PBL research reported above, coupled with a systematic effort to build a knowledge base that will be accessible and useful to people in the field.

References

Achilles, C. M., Hoover, S. P. (1996). Exploring problem-based learning (PBL) in grades 6-12. Paper presented at the Annual Meeting of the Mid-South Educational Research Association, Tuscaloosa, AL. (ED 406 406).

Ames, C. (1984). Competitive, cooperative, and individualistic goal structures: A cognitive-motivation analysis. In R. Ames & C. Ames (Eds.). Research in motivation in education: Student motivation (pp. 177-207). New York: Academic Press.

Ames, C. (1992). Classrooms: goals, structures, and student motivation. Journal of Educational Psychology, 84, 261-271.

Autodesk Foundation (1999). Kids who know and do--1999. Program for the 7th Annual Conference on Project-Based Learning, San Francisco. San Rafael: Autodesk Foundation.

Barron, B. J. S., Schwartz, D. L., Vye, N. J., Moore, A., Petrosino, A., Zech, L., Bransford, J. D., & The Cognition and Technology Group at Vanderbilt. (1998). Doing with understanding: Lessons from research on problem- and project-based learning. The Journal of the Learning Sciences, 7, 271-311.

Barrows, H. S. (1992). The tutorial process. Springfield, IL: Southern Illinois University School of Medicine.

Bartscher, K., Gould, B., & Nutter, S. (1995). Increasing student motivation through project-based learning. Master's Research Project, Saint Xavier and IRI Skylight. (ED 392 549).

Becker, H. J., Wong. Y. T., & Ravitz, J. L. (1999). Computer use and pedagogy in Co-NECT schools, A comparative study. Teaching, learning, and computing: 1998 National Survey Special Report. Irvine, CA: University of California.

Bereiter, C, (1990). Aspects of an educational learning theory. Review of Educational Research, 60, 603-624.

Bereiter, C. & Scardamalia, M. (1987). Intentional learning as a goal of instruction. In L. Resnick (Ed.). Motivation, learning and instruction: Essays in honor of Robert Glaser (pp. 361-392). Hillsdale: Lawrence Erlbaum Associates.

Bereiter, C. & Scardamalia, M. (1993). Surpassing ourselves: An inquiry into the nature and implications of expertise. Chicago: Open Court.

Bereiter, C. & Scardamalia, M. (1999). Process and product in PBL research. Toronto: Ontario Institutes for Studies in Education/University of Toronto.

Berger, R. (1996). A culture of quality. Occasional Paper No. 1, Providence, RI: Annenberg Institute for School Reform, Brown University.

Blumenfeld, P. C., Krajcik, J. S., Marx, R. W., & Soloway, E. (1994). Lessons learned: How collaboration helped middle grade science teachers learn project-based instruction. Elementary School Journal, 94, 5, 539-551.

Blumenfeld, P., Soloway, E., Marx, R., Krajcik, J., Guzdial, M., & Palincsar, A. (1991). Motivating project-based learning: Sustaining the doing, supporting the learning. Educational Psychologist, 26 (3&4), 369-398.

Boaler, J. (1997). Experiencing school mathematics; Teaching styles, sex, and settings. Buckingham, UK: Open University Press.

Boaler, J. (1998a). Alternative approaches to teaching, learning, and assessing mathematics. Paper presented at the European Conference for Research on Learning and Instruction. Athens, Greece.

Boaler, J. (1998b). Open and closed mathematics: Student experiences and understandings. Journal for Research in Mathematics Education, 29, 41-62.

Boaler, J. (1999). Mathematics for the moment, or the millennium? What a British study has to say about teaching methods. Education Week, March 31, 1999.

Boyce, L. N., VanTassel-Baska, J., Burruss, J. D., Sher, B. T., & Johnson, D. T. (1997). Journal of the Education of the Gifted, 20, 363-379.

Bransford, J. D. Sherwood, R. S., Hasselbring, T. S., Kinzer, C. K. & Williams, S. M (1990). Anchored instruction: Why we need it and how technology can help. In D. Nix & R. Spiro (Eds.). Cognition, education, and multimedia: Exploring ideas in high technology, (pp. 115-141). Hillsdale, NJ: Lawrence Erlbaum Associates.

Brown, A. L. (1992). Design experiments: Theoretical and methodological challenges in creating complex interventions in classroom settings. Journal of the Learning Sciences, 2, 141-178.

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

Brown, J. S. , Collins, A. & Duguid, P. (1989) Situated cognition of learning. Educational Researcher, 18, 32-42.

Cincinnati Public Schools. (1999). New American Schools designs: An analysis of program results in district schools. Cincinnati Public Schools.

Cognitive and Technology Group at Vanderbilt University. (1992). The Jasper series as an example of anchored instruction: Theory, program description, and assessment data. Educational Psychologist, 27, 291-315.

Cognitive and Technology Group, Learning Technology Center, Peabody College of Vanderbilt University. (1991). Technology and the design of generative learning environments. Educational Technology, 31, (5), 34-40.

Collins, A., Brown, J. S., & Newman, S. (1991). Cognitive apprenticeship: Teaching the crafts of reading, writing, and mathematics. In L. B. Resnick (Ed.) Motivation, learning and instruction: Essays in honor of Robert Glaser. (pp. 453-494). Hillsdale: Lawrence Erlbaum Associates.

Diehl, W., Grobe, T., Lopez, H., & Cabral, C. (1999). Project-based learning: A strategy for teaching and learning. Boston, MA: Center for Youth Development and Education, Corporation for Business, Work, and Learning.

Edelson, D. C., Gordon, D. N, & Pea, R. D. (1999). Addressing the challenge of inquiry-based learning. Journal of the Learning Sciences, 8, 392-450.

Expeditionary Learning Outward Bound (1997). Expeditionary Learning Outward Bound: Evidence of Success. Cambridge, MA: Expeditionary Learning Outward Bound.

Expeditionary Learning Outward Bound (1999a). A design for comprehensive school reform. Cambridge, MA: Expeditionary Learning Outward Bound.

Expeditionary Learning Outward Bound (1999b). Early indicators from schools implementing New American Schools Designs. Cambridge, MA: Expeditionary Learning Outward Bound.

Gallagher, S. A., Stepien, W. J., & Rosenthal, H. (1992). The effects of problem-based learning on problem solving. Gifted Child Quarterly, 36, 195-200.

Gallagher, S. A., Stepien, W. J., Sher, B. J., & Workman, D. (1995). Implementing problem based learning in science classrooms. School Science and Mathematics, 95, 136-146.

Gardner, H. (1991). The unschooled mind. New York: Basic Books.

Glaser, R. (1988). On the nature of expertise. In C. Schooler & W. Schaie (Eds.). Cognitive functioning and social structure over the life course. Norwood, NJ: Ablex.

Gordon, R. (1998). Balancing real-world problems with real-world results. Phi Delta Kappan, 390-393.

Guzdial, M, (1998). Technological support for project based learning. In C. Dede (Ed.). Learning with Technology, (pp. 47-72), Alexandria, VA: ASCD.

Hertzog, N. B. (1994). Impediments to a project-based and integrated curriculum: A qualitative study of curriculum reform. Paper presented at the Annual Meeting of the American Educational Research Association, New Orleans. ED369185.

Hmelo, C. E., Guzdial, M. & Tums, J. (1998). Computer support for collaborative learning: Learning to support student engagement . Journal of Interactive Learning Research, 9 (2), 107-129.

Horan, C., Lavaroni, C.. & Beldon, P. (1996). Observation of the Tinker Tech Program students for critical thinking and social participation behaviors. Novato, CA: Buck Institute for Education.

Jones, B. F., Rasmussen, C. M., & Moffitt, M. C. (1997). Real-life problem solving.: A collaborative approach to interdisciplinary learning. Washington, DC: American Psychological Association.

Klein, D. C. D., O'Neil, H. F., Dennis, R. A., & Baker, E. L. (1997). The five families of cognitive learning: A context in which to conduct cognitive demands analysis of technologies. Paper presented at the Annual Meeting of the American Educational Research Association, Chicago.

Krajcik, J. S., Blumenfeld, P. C., Marx, R. W., Bass, K. M., Fredricks, J., & Soloway, E. (1998). Inquiry in project-based science classrooms: Initial attempts by middle school students. The Journal of the Learning Sciences, 7, 313-350.

Krajcik, J. S., Blumenfeld, P. C., Marx, R. W., & Soloway, E. (1994). A collaborative model for helping middle-grade science teachers learn project-based instruction. The Elementary School Journal, 94, 483-497.

Ladewski, B. G., Krajcik, J. S., & Harvey, C. L. (1994). A middle grade science teacher's emerging understanding of project-based instruction. The Elementary School Journal, 94, 5, 498-515.

Linn, M. C. (1986). Computer as lab partner project. Teaching thinking and problem solving. Hillsdale, NJ: Lawrence Erlbaum Associates.

Ljung, E. J., & Blackwell, M. (1996). Project OMEGA: A winning approach for at-risk teens. Illinois School Research and Development Journal, 33, 15-17.

Marx, R. W., Blumenfeld, P. C., Krajcik, J. S., Blunk, M., Crawford, B., Kelley, B., & Meyer, K. M. (1994). Enacting project-based science: Experiences of four middle grade teachers. Elementary School Journal, 94, 517-538.

Marx, R. W., Blumenfeld, P. C., Krajcik, J.S., & Soloway, E. (1997). Enacting project-based science: Challenges for practice and policy. Elementary School Journal, 97, 341-358.

Meyer, D. K., Turner, J. C., & Spencer, C. A. (1997). Challenge in a mathematics classroom: Students' motivation and strategies in project-based learning. The Elementary School Journal, 97, 5, 501-521.

Moore, A., Sherwood, R., Bateman, H., Bransford, J., & Goldman, S. (1986). Using problem-based learning to prepare for project-based learning. Paper presented at the Annual Meeting of the American Educational Research Association, New York.

Moursund, D. (1999). Project-based learning using information technology. Eugene, OR: International Society for Technology in Education.

New American Schools Development Corporation (1997). Working towards excellence: Results form schools implementing New American Schools Designs. New American Schools Development Corporation.

Peck, J. K., Peck, W., Sentz, J., & Zasa, R. (1998). Students' perceptions of literacy learning in a project based curriculum. In E. G. Stutevant, & J. Dugan (Eds.). Literacy and community: The twentieth yearbook: A peer reviewed publication of the College Reading Association, (pp. 94-100). Carrollton, GA: Beacon.

Penuel, W. R., & Means, B. (2000). Designing a performance assessment to measure students' communication skills in multi-media-supported, project-based learning. Paper presented at the Annual Meeting of the American Educational Research Association, New Orleans.

Petrosino, A. J. (1998). The use of reflection and revision in hands-on experimental activities by at-risk children. Unpublished doctoral dissertation. Vanderbilt University, Nashville, TN.

Polman, J. & Pea, R. D. (1997). Transformative communication in project science learning discourse. Paper presented at the Annual Meeting of the American Educational Research Association, Chicago. (ERIC ED407283).

Rosenfeld, M. & Rosenfeld, S. (1998). Understanding the "surprises" in PBL: An exploration into the learning styles of teachers and their students. Paper presented at the European Association for Research in Learning and Instruction (EARLI), Sweden.

Rosenfeld, S., Scherzo, Z., Breiner, A., & Carmeli, M. (1998). Integrating content and PBL skills: A case study of teachers from four schools. Paper presented at the European Association for Research in Learning and Instruction (EARLI), Sweden.

Ross, S. M. et al. (1999). Two- and three-year achievement results on the Tennessee value-added assessment system for restructuring schools in Memphis. Memphis: Center for Research in Educational Policy, University of Memphis.

Rugen, L. & Hartl, S, (1994). The lessons of learning expeditions. Educational Leadership, 52, 20-23.

Sage, S. M. (1996). A qualitative examination of problem-based learning at the K-8 level: Preliminary findings. Paper presented at the Annual Meeting of the American Educational Research Association, New York. (ED 398 263).

Savey, J. R. & Duffy, T. M. (1985). Problem based learning: An instructional model and its constructivist framework. Educational Technology, 35 (5), 31-38.

Savoie, J. M. & Hughes, A. S. (1994). Problem-based learning as a classroom solution. Educational Leadership, 52 (3) 54-57.

Scardamalia, M., & Bereiter, C. (1991). Higher levels of agency for children in knowledge building: A challenge for the design of new knowledge media, Journal of the Learning Sciences, 1, 37-68.

Scardamalia, M., Bereiter, C., McLearn, R. S., Swallow, J., & Woodruff, E. (1989). Computer supported intentional learning environments. Journal of Educational Computing Research, 5, 51-68.

Shepherd, H. G. (1998). The probe method: A problem-based learning model's effect on critical thinking skills of fourth- and fifth-grade social studies students. Dissertation Abstracts International, Section A: Humanities and Social Sciences, September 1988, 59 (3-A), p. 0779.

Stepien, W. & Gallagher, S. (1993). Problem-based learning: As authentic as it gets. Educational Leadership, 51, 25-28.

Stepien, W. J., Gallagher, S. A., & Workman, D. (1993). Problem-based learning for traditional and interdisciplinary classrooms. Journal for the Education of the Gifted, 16, 338-357.

Thomas, J. W. & Mergendoller, J. R. (2000). Managing project-based learning: Principles from the field. Paper presented at the Annual Meeting of the American Educational Research Association, New Orleans.

Thomas, J. W., Mergendoller, J. R., and Michaelson, A. (1999). Project-based learning: A handbook for middle and high school teachers. Novato, CA: The Buck Institute for Education.

Torp, L. & Sage, S. (1998). Problems as possibilities: Problem-based learning for K-12 education. Alexandria, VA: Association for Supervision and Curriculum Development.

Tretten, R. & Zachariou, P. (1995). Learning about project-based learning: Self-assessment preliminary report of results. San Rafael, CA: The Autodesk Foundation.

Tretten, R. & Zachariou, P. (1997). Learning about project-based learning: Assessment of project-based learning in Tinkertech schools. San Rafael, CA: The Autodesk Foundation.

Udall, D. & Mednick, A. (1996). Journeys through our classrooms. Dubuque, IA: Kendall/Hunt.

Udall, D. & Rugen, L. (1996). Introduction. In D. Udall & A. Mednick (Eds). Journeys through our classrooms. (pp. xi-xxii), Dubuque, IA: Kendall/Hunt.

Williams, D. C., Hemstreet, S., Liu, M., & Smith, V. D. (1998). Examining how middle schools students use problem-based learning software. Proceedings of the ED-MEDIA/ED-Telecom 98 World Conference on Educational Multimedia and Hypermedia, Frieburg, Germany. (ED 428 738).

Williams, S. M. (1992). Putting case-based instruction into context: Examples from legal and medical education, The Journal of the Learning Sciences, 2, 367-427.