A Computer-Mediated Support System for Project-Based Learning

☐ James Laffey
Thomas Tupper
Dale Musser
John Wedman

Project-based learning places demands on learners and instructors that challenge the traditional practices and support structures of schools. Learning from doing complex, challenging, and authentic projects requires resourcefulness and planning by the student, new forms of knowledge representation in school, expanded mechanisms for collaboration and communication, and support for reflection and authentic assessment. This article describes a computer-mediated learning-support system designed as a suite of integrated, internet-based client-server tools to provide (a) intelligent support both for the processes of doing a project and for learning from doing a project, and (b) a shared dynamic knowledge base for working and learning in a community supporting project-based education. The article describes the architecture of the system, its current state of development, and findings from an initial deployment. This articulation of the system components and findings can benefit several groups. It can help (a) educators envisioning the role of technology in augmenting authentic forms of learning, (b) developers of other support systems as they compare features and implications, and (c) researchers as they frame questions about human-computer interactions in learning systems.

☐ Students, as well as scientists, learn science by observing and doing scientific work, by being engaged in a community of knowledge seekers, and by being challenged to solve problems that enrich themselves and their communities. The National Science Education Standards call for learning science by *doing* science that is meaningful and authentic. "Schools that implement the Standards will have students learning science by actively engaging in inquiries that are interesting and important to them." (National Research Council, 1996). Educators are challenged to transform schools into places where students encounter knowledge and build skills by engaging in authentic, context-based inquiry. Unfortunately, the traditions, structures, and processes of schools do not support student-directed inquiry that employs authentic contexts and practices. Without new processes and support tools, significant reforms like those called for by the science education community are unrealistic and unlikely to take place.

This paper describes work underway to articulate the processes of teaching and learning science through the use of authentic project-based inquiry, and describes a software application for supporting these processes. This work is being carried out as part of Project MOST (Missouri Supporting Teachers) (Laffey, 1995a), a National Science Foundation (NSF) supported effort (NSF REC 9554313) to assist high school teachers and students engaged in project-based teaching and learning.

EDUCATIONAL NEED

Traditional schooling represents real phenomena and processes at a high level of abstraction. Schools divide knowledge and understanding into subject matters and grade levels, which are further subdivided into chapters, lessons, exercises, drills, and the like. Such abstraction and simplification may allow more students to grasp and be successful with artificial, school-based problem sets, but at the cost of decontextualization and oversimplification (Collins, 1996). As Resnick (1987) has pointed out, traditional school learning too often fails to prepare students for the kind of learning and performance that is required outside of school. This outside-of-school learning and performance usually involves shared cognition, tool manipulation, contextualized reasoning, and situation specific competencies. Wiggins (1993), in arguing for authentic assessment practices, stated that ". . . we cannot be said to understand something unless we can employ our knowledge wisely, fluently, flexibly, and aptly in particular and diverse contexts." The result of the abstraction of knowledge and experience that typifies most school curricula is that students are denied true participation in a fully authentic context, and the outcomes of the learning processes are fragile.

Researchers who study learning outside of traditional school settings are coming to see how the authenticity of the learning activity and context are integral components of cognition and learning outcomes. Learning is fundamentally situated, and the production of useable and robust knowledge is supported by tasks and environments that are authentic (Brown, Collins, & Duguid, 1989). Authenticity in school curricula is supported by: (a) investigations that are open-ended; (b) answers that are not predefined; (c) student construction of meaning; and (d) student use of scientific tools and techniques involving them in scientific discourse and collaboration. In contrast, conventional learning environments tend to involve "canned" experiments and decontextualized problems that deny students the opportunity to work on authentic problem sets using the tools and techniques of real science (Spitulnik et al., 1995). Project-based learning provides an approach for addressing such decontextualization, but also presents unique challenges to students and instructors which overwhelm the cognitive and physical support structures found in contemporary schools. These structures, while supporting the curricula typically found in schools, do not provide for the demands and variety of work that accompany authentic science exploration. Rather than abstracting the work of real scientists, packaging and simplifying it for the classroom, project-based curricula demand supports of various kinds that allow learners to engage in meaningful, authentic work (Collins, Brown, & Newman, 1989).

WHAT IS PROJECT-BASED LEARNING?

Project-based learning is a form of contextual instruction that places great emphasis on student problem-finding and framing, and which is often carried out over extended periods of time. Blumenfeld et al. (1991) described project-based learning as centered on relatively long-term, problem-focused, meaningful units of instruction that integrate concepts from a number of disciplines or fields of study. "Students pursue solutions to authentic problems by asking and refining questions, debating ideas, making predictions, designing plans and/or experiments, gathering information, collecting and analyzing data, drawing conclusions, and communicating their ideas and findings to others." (Krajcik, Blumenfeld, Marx, & Soloway, 1994, p. 483).

Project MOST (Laffey, 1995a) is an NSF-supported effort focusing on project-based learning in the interdisciplinary area of computational science. The teachers involved in Project MOST were selected based on their commitment to realizing the potential of project-based curricula for their students. While concerned with curriculum coverage, Project MOST teachers highly value work that helps students learn how to (a) solve or address challenging, authentic problems using scientific knowledge and methods, and (b) work on a project over time (several months to a year), on a team, using technology tools (Internet, visualization, analysis, communication, modeling, etc.). Summarized below, the challenges that confront the teachers and students as they engage in project-based inquiry require new skills, approaches, resources, and support systems.

Teachers need help to be coaches and facilitators. A workshop held by the National Science Foundation on educational technology summarized the general need by stating that "teachers will need substantial support to shift from traditional teaching to roles emphasizing: facilitation; in-depth assessment of student understanding; and coordination of multiple sources of learning support" (Hawkins, 1995). How do teachers act as role models, manage multiple projects, consult in areas of limited expertise, guide with feedback, promote teamwork, recognize and intervene when problems arise, and in general "shepherd" projects rather than drive them?

Students need support for taking on the whole project, not just carrying out tasks assigned by the teacher. What encourages and supports them as they take on a challenge in a rigorous way? Students need to draw from their own personal experience and interests, yet fit a project within curriculum objectives. They need to organize and do the work of the project; they need to collaborate with peers and find mentors, resources, and guidance in order to achieve quality outcomes. They also need to make sense of their results and transform project efforts into valued products and results. The Project-Based Learning Support System (PBLSS) was created to help meet the needs of teachers and students engaged in project-based learning.

WHAT IS PBLSS?

The Project-Based Learning Support System is a client/server software application that integrates a number of tools designed to assist students involved in investigations that closely parallel the work of real researchers. Such investigations take extended periods of time and consist of multiple factors requiring diligent attention. They also place strong demands on the cognitive resources of the researcher, and require collaboration; success often depends on skill and experience. PBLSS represents an attempt to support learning through authentic science inquiry, and to make these supports available through a computer-mediated interface. As a system it borrows heavily from work in electronic performance support (Gery, 1991, Laffey, 1995b) and learner-centered software design (Jackson, Stratford, Krajcik, & Soloway, 1995), as well as from the ideas about authentic working and cognitive apprenticeship illustrated by Brown et al. (1989) and underlain by the work of Vygotsky (1978).

THE PBLSS SUPPORT ARCHITECTURE

PBLSS includes support for two instructional processes and four learning processes. The instructional processes are (a) scaffolding and (b) coaching. The learning processes are (a) planning and resourcefulness, (b) knowledge representation, (c) communication and collaboration, and (d) reflection. These processes and the associated PBLSS supports are summarized in Table 1 and discussed in the following sections.

Scaffolding

Collins et al. (1989) characterized scaffolding as a process where an expert performs part of a complex task for which a learner is unprepared, thereby allowing learners to engage in work that would normally be outside their grasp. Scaffolding can take the form of a suggestion or other discourse-based assistance. It can also appear in the form of physical support, such as cue cards (Scardamalia, Bereiter, & Steinbach, 1984) or specialized devices such as the short skis used in teaching downhill skiing (Burton, Brown, & Fischer, 1984). Scaffolding is therefore any tool, procedure, or aspect of the learning environment that is specifically engineered to assist learners in performing tasks for which they would otherwise be unprepared.

Explicit forms of instructional scaffolding—those delivered primarily through interaction with an advisor or expert—represent only one kind of scaffolding. Procedure and task facilitation, realized through physical and structural supports that are *implicit* to the design of an interface, are also forms of scaffolding. This extended notion of scaffolding, which includes the designed structure of an environment for learning or performance, is based on the recognition that humans have always worked with

Table 1 ☐ Processes of the Project-Based Learner Support (PBLSS) Architecture

Processes	Definitions	Methods
Instructional		
Scaffolding	Structural supports to assist novice learners in the performance of tasks for which they would otherwise be unprepared.	• Interface design broadly scaffolds the steps of a project, the language of real science, and concerns which must be addressed in order for a project to be successful.
Coaching	Situated responses to learner task performances which are targeted at bringing learner performance closer to expert performance.	• Advanced, interactive help system that is context/task sensitive. • Immediate feedback targeted at improving the use of the tools themselves. • Immediate feedback targeted at explaining/scaffolding/supporting performance at various project tasks. • Context sensitive guidance system.
Learning		
Planning & Resourcefulness	Tools designed to assist learners with the complex demands involved in planning and being resourceful within authentic research projects.	• Scheduling tools for establishing specific objectives and their start and stop dates. • Resources tool for specifying material and information resources necessary for the project, with linking to specific objectives. • Team member/member responsibility specification tool.
Knowledge Representation	Tools designed to assist learners in the framing, representation, and re-representation of their ideas, knowledge, and their development, and in deriving cognitive benefits from the act of representation.	• Sections for representation of a project abstract, project goals, objectives, resources, and applications/extensions of the work. • Multiple representational formats via native documents and automatically generated/uploaded WWW pages. • Scaffolding, coaching, and guidance systems fully integrated to assist in the representation process.
Communication & Collaboration	Tools designed to support the exchange and sharing of ideas and results, collaboration between widely distributed participants, feedback, discussion, & debate, and the growth of a "community" of learners.	• World-Wide-Web based comment forms. • Site customizable, threaded, public and private discussion groups with embeddable URL's for resource sharing. • Integrated email with address book and embeddable URL's. • Integrated point-to-point and group real-time chat facilities.
Reflection	Tools to support self and communal evaluation and reification of previously completed work, with subsequent cognitive and physical revision, re-framing, and restructuring of ideas, assumptions and representations.	• Tracking and storage of all revisions to a team's work. • Multiple-window views for comparison of old and new work. • Sharing of all work, including old and new revisions, with the larger community. • Scaffolding, coaching, and guidance systems fully integrated to assist in the reflection process.

objects (e.g., counting on our fingers) to extend cognitive powers (Norman, 1993). Today, advances in technology are providing machine affordances that shape how we think and what we value. Therefore, insofar as the affordances of a designed environment act to shape and guide thinking and action, the environment itself can be said to implicitly scaffold.

The current version of PBLSS uses implicit rather than explicit forms of scaffolding. The interface is designed around a set of procedures that scaffold the process of doing science projects. These processes include setting goals, breaking complex goals down into achievable objectives, planning for these objectives by allocating time for periods of work, and anticipating and planning for the resources that must be available for an objective to be reached. They also include representing one's work using the standards of the community, communicating one's ideas and findings to other members of the community, and working with other members of one's community as a member of a research team when confronted by difficult problems that require expertise outside one's own domain. These processes are central to the practice of science, and to the experience of the scientist. The case may also be argued that some of these processes (e.g., representation, collaboration, reflection) are fundamental to building new knowledge and to refining the individual and communal understanding of knowledge that was previously built (Dewey, 1933, 1938; Schön, 1983). By providing a framing structure and support for these processes, PBLSS scaffolds some of the work of real science.

Coaching

Coaching refers to a range of activities including modeling, giving feedback, structuring the way to do things, challenging the learner, providing hints, encouraging, providing reminders, and diagnosing problems (Collins, Brown, & Newman 1989; Collins, 1996). Coaching usually involves highly situated responses to learner task performances; responses targeted at bringing learner performance closer to expert performance. Often conceived of as possessing a quality of immediacy, the coaching interaction is usually delivered promptly whenever specific problems or events arise as the student attempts to perform a task. Coaching can be performed after the fact, however, as when a basketball coach reviews a previous game with the team, discussing mistakes and suggesting methods for improvement. It can also be done in *preparation* for a performance. Thus, coaching can be done both a priori and a posteriori, and can be either immediate or delayed.

PBLSS implements coaching both through its structure (which models tasks) and through feedback and guidance. The feedback methods employed occur both a priori and a posteriori to specific events, but are always delivered immediately. At present, most coaching in PBLSS supports the development of expert performance in the use of the tool itself. Additional coaching is provided to assist learners engaged in representational tasks. For example, Figure 1 shows how assistance can be provided for representational tasks such as creating an abstract to briefly describe one's project. This assistance is available when the student needs to create an abstract and in the environment used for creating the abstract.

Coaching is also supported in PBLSS via communicating student work to the teacher in forms that support the instructional decision-making process. The approaches to communication and collaboration that PBLSS implements (discussed later) provide easy, consistent, and rapid access to student work by the teacher. Using an Internet browser the teacher can review the student's work, see previously made comments, and leave new comments. Thus, PBLSS helps represent student work and changes in it in ways that are easy for the teacher to access and understand, and which facilitate the coaching process.

Planning and Resourcefulness

Most students have never taken on a long-term project where the work has not already been essentially scripted by the teacher or curricular material. They have little practice at doing projects and are not adept at managing the many components that require attention. They therefore need tools specialized for the task of helping novice researchers with the complex management tasks of an authentic research project. PBLSS addresses the complexities of real scientific investigations by providing organizational and management tools for project planning and resourceful implementation. Since a project is not a scripted task, planning tools need to be open ended and enable modification and redirection. PBLSS provides tools of this sort. Specifically, PBLSS provides tools for specifying broad goals, for specifying sets of objectives and associated time-lines that are steps to be accomplished in the meeting of those goals, and for specifying and associating resources that must be available if the objectives are to be met. One such PBLSS tool is the objectives editor shown in Figure 2. The objectives editor allows the learner to specify objectives, provide a time period, and identify key resources needed to accomplish the objective. As Figure 2 indicates, the student can

Figure 1 ☐ An example of coaching within PBLSS.

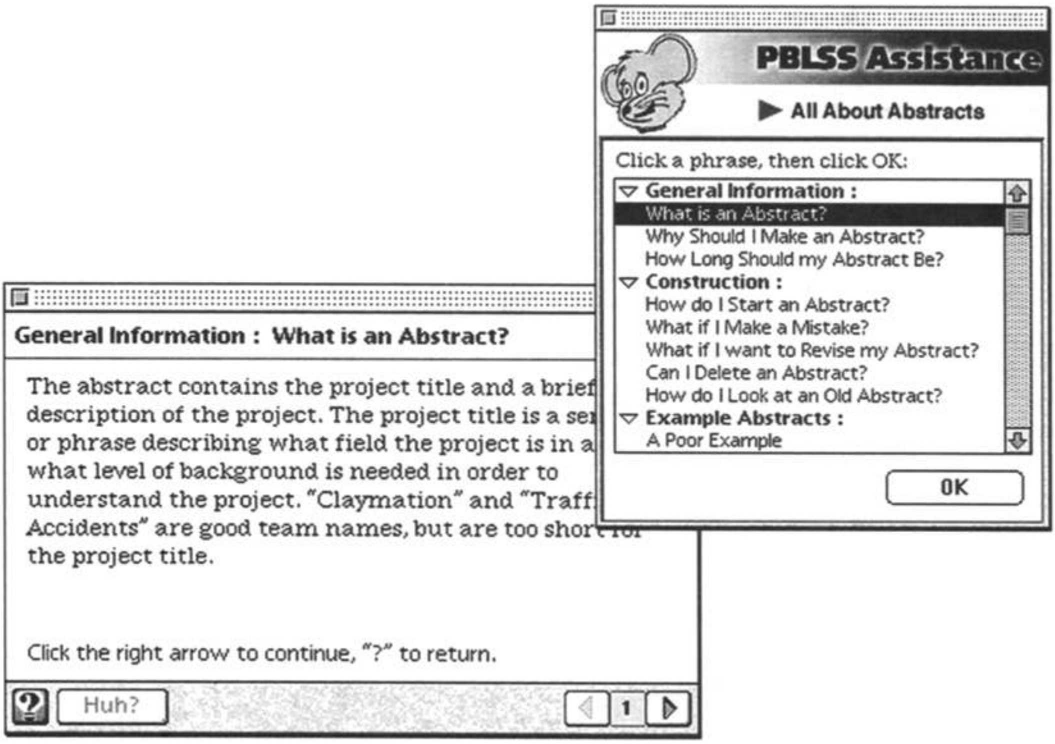
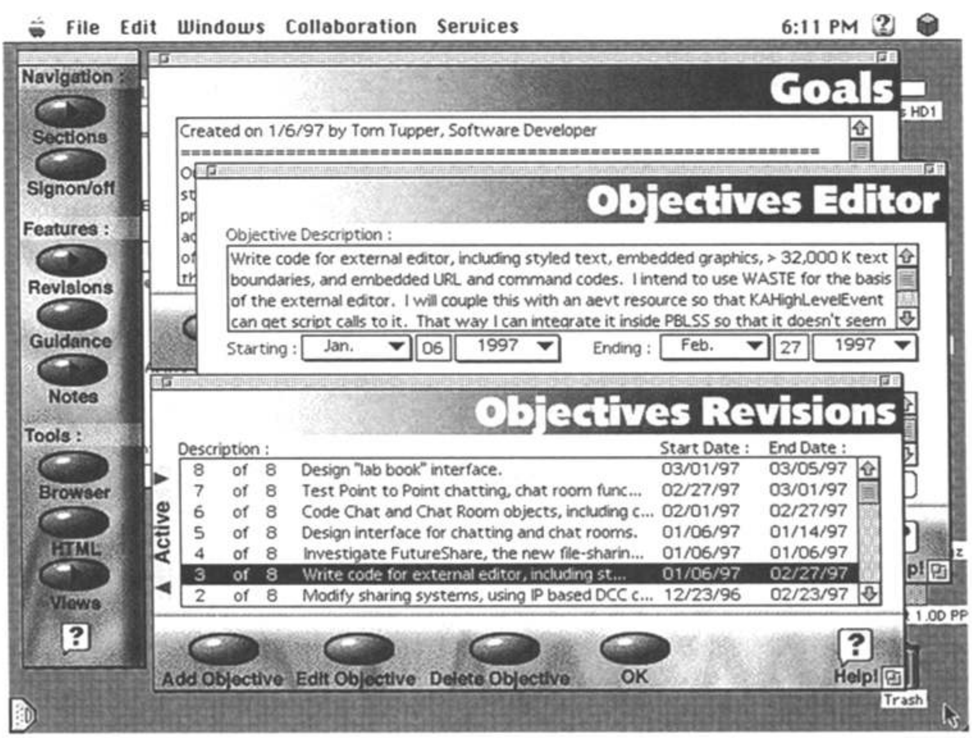


Figure 2 ☐ Portions of PBLSS interface related to planning and resourcefulness.



maintain and organize plans for multiple objectives.

Knowledge Representation

Educators sometimes think of knowledge representation statically. The student either has the correct representation (i.e., one that matches the teacher's) or does not. We believe, however, that learning is an act of coming to know, and of representing knowledge by creating an abstraction that captures thoughts, perceptions, and experience apart from irrelevant detail. Constructing and representing knowledge is fundamental to learning and is the essence of higher-order thought (Norman, 1993). A representation, once created, becomes a cognitive artifact and can function as a tool for thought. Transferable from one learner to the next, or from one context to the next, a representation can act as a lens to focus and guide inquiry. Scientific journals are a case in point. The act of creating a manuscript—a representation—requires (for most of us) significant deep processing and reflective thought, while the end product of that process, a journal article, acts as a cognitive tool for the other learners in our community. This is true of most representations; almost all can be seen as both the product and antecedent of cognition.

The process of creating most artifacts, which we take to be synonymous with the act of representation, requires a number of cognitive processes to occur. Students engaged in constructing artifacts must assimilate new information, integrate it into their knowledge base, build connections between concepts and ideas, and restructure their understanding when confronted by ideas that do not fit within their current conceptual framework (Spitulnik et al., 1995). These activities—what Norman (1993) calls accretion, tuning, and restructuring—are fundamental processes of learning.

PBLSS supports knowledge representation by helping learners organize their thoughts into an analogue of a journal article that includes sections for an abstract, a statement of project goals, a listing of specific objectives, project time-lines, the resources needed to accomplish objectives, specification of the project team and responsibilities of the members, and an applications/extensions section in which they may draw conclusions from their work and make suggestions for further inquiry. Facility is provided for note taking concerning the process of the project and metacognitive analysis of the work in progress, as well as the explanation of purely administrative activities. The revisions that learners make to these portions of their "documents" are tracked over time, and are available to the members of the research team (or the teacher) at any time. PBLSS also enables students to represent their work in several forms, both as native PBLSS documents (for use by the PBLSS client application) (see Figure 3 left) and as HTML for posting to the World Wide Web (see Figure 3 right).

Communication and Collaboration

Scientists communicate with each other regarding their hypotheses and suppositions, and bond around problems or interests into geographically dispersed communities of scholars and knowledge seekers. These *communities of practice* are bound by complex social webs. An understanding of what such practitioners do cannot be derived without understanding the culture of practice that binds them (Geertz, 1983). Immersion in that culture is essential if learners are to build and use the conceptual tools of science as scientists use them (Brown et al., 1989). Enabling the same kinds of communities established by scientists for learners engaged in a project-based curriculum is important if we are to provide authentic immersion in the domain. But the benefits of enabling this *community of learners* can reach far beyond the added authenticity it provides. Social discourse can provide important points of divergence for intellectual growth, challenge students to think more deeply about what they are doing, and spark reflection and restructuring of previously held beliefs in the domain. Furthermore, the existence of this community, and of the underlying technological infrastructure that supports it, provides for collaboration among learners across great distance, for telementoring, and for the growth of a "culture of thinking" (Perkins, 1993).

PBLSS provides site customizable, threaded,

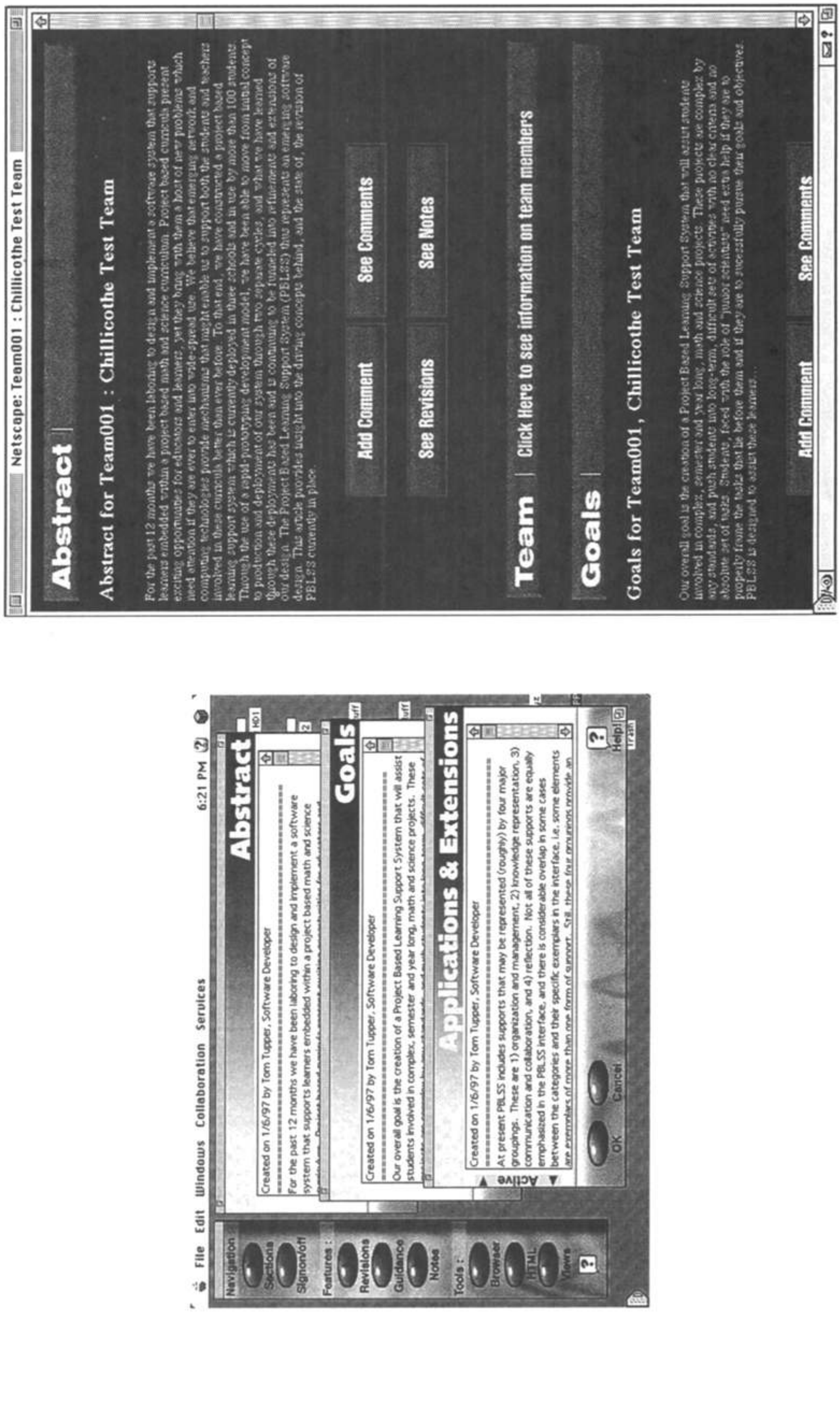
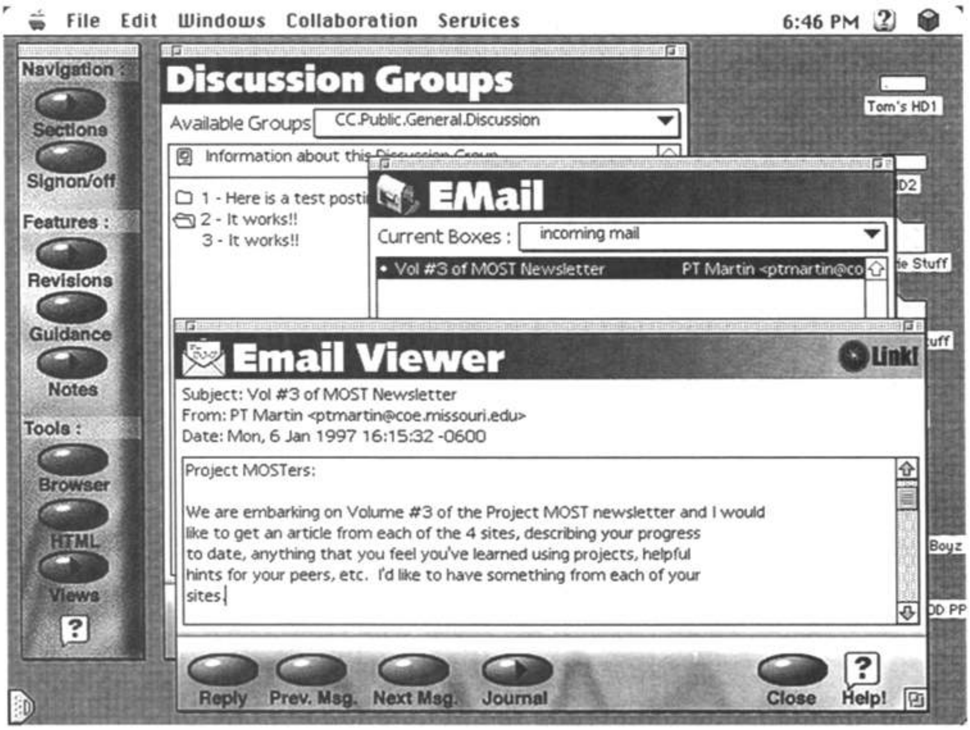


Figure 3 ☐ The PBLSS Client and associated Web-representations of project components.

Figure 4 ☐ PBLSS collaboration and communication tools.



topic-based discussion groups to enable discourse and information sharing. Every PBLSS research "team" is provided with both a public and a private discussion area so that team members can privately discuss their research or publicly disclose it, opening up their efforts to the community at large. In addition to these groups, each PBLSS site can specify any number of public access discussion spaces that provide for special interest groups, help areas, or whatever the teachers and students at a specific site may wish. In addition, teachers and students from several sites can elect to share some or all of their discussion areas, allowing students from different sites to collaborate electronically (see Figure 4). In addition to the discussion groups provided within PBLSS, there is a robust e-mail tool that is fully integrated into the interface. Further, a team's work can be automatically represented on the World Wide Web, facilitating discussion and commentary via *add a comment* links that allow any browser examining the team's work to make comments about any aspect of it. These comments are stored as more-or-less permanent parts of the team's Web representation of their project.

Reflection

Although the act of knowledge representation often requires what Norman (1993) dubbed reflective cognition, knowledge representation does not automatically engage students in looking back over their work and making critical appraisals and comparisons of the work to that of others, or to their own internal cognitive model of expertise. This kind of "reification" (Collins, 1996) or "abstracted replay" (Collins & Brown, 1988) enables a learner to reflect in a systematic way on the problem-solving process, and to reach new conclusions or make elaborations they might otherwise not have. Reificative reflection brings powerful cognitive forces into play. Learners examining their own work and comparing it to that of others, to their own later work, or to a cognitive model, must organize information, elaborate upon concepts, and integrate ideas from potentially many sources.

In our work with Project MOST schools we have found evidence to support the assertion that reificative reflection serves to assist students in refining their understanding of their work. Consider the following two excerpts from a team's abstract of its project on cardiovascular fitness: one done before reflection upon the team's project and working process, and one after.

Abstract before reflection:

Exercising right to obtain the best possible workout is a problem in today's society. People exercise in many different ways to obtain the most performance out of the least amount of activity. Unfortunately, it is not readily known which type of workouts provide this type of cardiovascular fitness. Our project is done in the hopes of providing some of this data. Using workouts involving running and biking, we measured the maximum heart rate, and the time it takes to return to the resting heart rate (recovery time). The comparison of the recovery times [are] used to compare the merits of each exercise, to see which provides the best results over the limited time we conducted the experiment.

Compare this original treatment of the team's project with the treatment provided after reflection. For brevity's sake, only *part* of the postreflection characterization is shown here.

Abstract after reflection :

The research done for this project was done primarily to obtain an understanding of the idea behind training. Training is done for the purpose of increasing the maximum oxygen intake of the body. Extensive training leads to a reduction of heart rate, a lower blood pressure, an increase in stroke volume, and a quicker recovery time from training. All of these results are interrelated. By training, the heart is strengthened to the point that each pump of heart pushes more blood throughout the body than before the training. This makes it possible for more oxygen to get to every part of the body in less time. Thus while not training, less heart beats are needed to spread blood throughout the body, and while training, the heart is able to supply the blood the body needs during increased action. When this action is finished, the body is able to replenish the depleted oxygen in the body quicker with the strengthened heart—the recovery time. In this way, a strengthened heart makes for a healthier body. Since a strong heart is healthy, ways of conditioning the heart are desired, especially ways that are effective in the least amount of time. Two methods exist for building up the cardiovascular system: isometric and dynamic. Isometric exercise is done through muscle contractions without movement, such as squeezing hand grips. Dynamic, the most effective form, is the exercise done with movement, such as running and biking . . . .

The team's second abstract is much more complete than the first, covering the general rationale and guiding problem of the project more thoroughly. It contains significantly more substantive content (expressions of concepts, etc.), which is more strongly represented and better elaborated. Explanatory ideas such as oxygen intake, blood pressure, stroke volume, and so forth are also present, whereas they were completely absent in the first representation. These changes happened over a number of periods of reflective processing, and occurred in the context of a rerepresentation of the original work. They therefore illustrate quite nicely the cumulative payoff of reificative reflection and representation in bettering student work.

PBLSS supports reflection by requiring students to articulate their work, by facilitating comments and critiques from others, and by making it easy to review and compare previous work. By having several discourse and collaboration channels, PBLSS increases the likelihood that the student's articulation will be reviewed and critiqued, thus encouraging further reflection. PBLSS provides for reificative reflection by tracking and storing every revision (in PBLSS revisions are major changes, not corrections or minor additions, etc.) made to a part of the research team's documents from the beginning of a project to its end. Thus, every revision of a team's abstract, for example, is stored along with any process comments that the team members may have entered about that revision. These revisions can be viewed at any time. Because PBLSS provides for a multiple-window representation of the team's work (see Figure 4), multiple revisions can be viewed simultaneously, enabling comparisons between them and corresponding reflective thought. Learners might pull up the first and last abstract revisions, compare them, and see how they changed over the life of the project. Or they might examine their goals as they changed over time. These kinds of examinations are not limited to the members of the research team. The Web representation of the team's work contains a complete record of that work over the life of the project. It can therefore be used by other interested parties to reconstruct the process, to see how the team and its project grew and changed over time, and to guide or model their own work.

FINDINGS FROM THE PBLSS IMPLEMENTATIONS

Two implementations of PBLSS were deployed during the first year of development. Our approach has been to develop a core set of functions and deploy these as rapidly as possible, so as to learn from real user experience. The first deployment of PBLSS occurred near the end of a school year and included 31 students in one school. The students were enrolled in a project-based learning course focusing on computational science. These students were asked to transfer their project contracts and other artifacts into PBLSS so as to test the fit of the PBLSS interface with the students' model of a project. The second implementation, which is ongoing, has PBLSS on-site for an entire school year and in use by more than 100 students in three schools. These students have completed their first semester, and their comments about PBLSS, along with our observations of their use of the tool, are leading to insights about the strengths and weaknesses of the current implementation.

Data from the First Deployment

Data were collected from the 31 students involved in the first deployment through the use of a 17-item Likert scale and a short answer questionnaire, and from semi-structured interviews. Of the 31 students surveyed, roughly 90% (n = 27) felt that the tool was average-to-easy to learn and use. Most (70%, n = 21) felt the tool was of average-use to very-useful, and most (76.7%, n = 23) said they would like to use the tool again in future projects. In examining *comments* from the students, ease-of-use was the most commonly reported feature of the software that students liked (n = 10), followed by the overall quality of the software's organization and presentation (n = 8), the appearance of the software (visual appeal, n = 5), the ability to output Web pages (n = 4), revision tracking (n = 3), and on-line instructions (n = 1). Negatives that were commonly reported centered around bugs in the software (n = 10), flexibility issues (n = 3), and the fact that representing the work was time consuming (n = 2).

The interviews confirmed the survey results suggesting that the students liked the tool and found it easy to use. Their positive remarks about the tool generally centered on its interface, the way it structured the representation task for them, and the way that the tool enabled them to generate multiple representations of their work easily. Again, most dislikes centered around the bugs in the software and what some students saw as limited flexibility in the representational structure of the tool. What was most interesting about the interview responses was, however, the students' views of where the tool fit in their work. Most students viewed the tool as a representational vehicle for their project's work, but they did not view it as a vehicle for furthering that work or as a tool to support them in the process of doing that work. It is possible that these views resulted from the nature of the students' interaction with the tool. They did not receive and begin using the tool until very late in the development of their work, and consequently did not have much opportunity to use it in the course of their projects. Most students were therefore able to use PBLSS only in a representational role, and probably did not benefit from its process scaffolding and structural supports. However, in retrospect it seems quite clear that these findings were largely consistent with the nature of the tool at the time, as it did not then provide many supports for process, lacked robust collaboration features, and was in character mostly geared towards representation.

Findings from the Current Implementation

Following the first deployment, bugs were fixed, some interface features were improved and a set of communication and collaboration tools was added to PBLSS. The postdeployment assessment for version 1.0, as well as reports obtained via informal assessments carried out during the deployment period, had revealed that students considered the software to be too buggy for serious use. We therefore refined the software and removed bugs prior to the second deployment. Interviews with teachers and students had also revealed strong interest in cross-class and cross-school collaboration on projects. The local-area network (LAN) based nature of PBLSS did not support such collaboration, so the decision was made to implement a set of Internet-based collaboration tools including integrated e-mail as well as public and private discussion groups.

The second deployment of PBLSS has been in place for one semester. Data have been collected through observation of student use, review of their PBLSS artifacts, and interviews with teachers and students. As with the first deployment, students have responded favorably to the interface and ease of use of the tool. Some students still find the representational structure limiting, while most have no serious complaints. Students seem to perceive the tool as both stable and easy to use. Unfortunately, they have tended to utilize the tool when desiring to represent their work formally, but have neither used it as a tool for representing the informal work of the team on a daily basis, nor when they need support for solving problems. Formalized representations, while they may be thought to have emerged from reflection and reification, do not adequately capture the process of the scientific endeavor. They provide neither a complete record of the work undertaken by the students, nor the thinking and group processes behind that work. We view these work efforts as among the most important and fundamental aspects of project-based learning. It is the process that provides rich opportunity for discovery and learning, provides occasion for reflection and rethinking, and leads to observable, authentic outcomes useful in assessment. While one function of a support system like PBLSS is to support and enrich the work the students are doing, another is to catalogue that work as it proceeds, providing a rich record of the project from beginning to end. Unfortunately, in capturing students' work as it proceeds PBLSS makes significant inroads, but still falls short of what is needed.

One finding that has significantly advanced our understanding of support systems for learners is that PBLSS is not sufficiently synchronized with the assessment procedures used in our Project MOST schools. Some of the products generated through the use of PBLSS are assessed by the teacher, but most of the processes assessed by teachers occur outside the PBLSS environment. For example, at several key points during a project, students create a concept map of their work, report it to a panel of reviewers, confer with those reviewers, and then reflect on and create representations of what they have learned. The students do not use PBLSS for this mapping, reviewing and reflecting, because they do not think that PBLSS provides appropriate tools. This limits the exposure students have to the PBLSS support architecture, and therefore reduces their chances of deriving benefit from it. Learner-support tools such as PBLSS do not always provide obvious advantages to learners, who may be focused on the tasks at hand rather than the eventual learning outcome. The tools, therefore, must be tightly woven into the curriculum. Such tools must directly address those parts of student work that yield value and lead to assessment or they will only be seen as peripheral to the learner's work. Further, if a support system is to be effective in capturing student work and thinking as it unfolds and grows, it must provide tool sets that fit naturally into the primary working patterns and daily chores of the students, and that support any assessment methodology (whether it be from the teacher or self assessment by the students) that is in place. Our experience has been that most students are economical with their time. They focus most intently on the tasks required of them for assessment purposes, and perform other activities only as time permits. Mismatches occurring between the tasks required of students for their assessment and those enabled by the electronic support system, regardless of the pedagogical soundness of the methods utilized therein, will reduce the utility of the tool and its effectiveness.

LOOKING AHEAD

PBLSS has been, despite some disappointments, a very successful software system both for supporting some aspects of project-based learning and for articulating the processes that underlie doing authentic projects in school. Findings from the field deployments of PBLSS have advanced our understanding of the basic proposition that technology can be used to scaffold authentic inquiry in school environments, and have helped us refine our model of technologically assisted learning. We plan revisions of the software to advance the benefits it provides to teachers and students, and to test revised models of the learner-support architecture.

PBLSS is an attempt to support both the student and teacher engaged in project-based learning. It places great emphasis on students' representation of their work, both alone and in the context of interclass and interschool collaboration. Although both students and teachers could envision such collaboration, and even asked for it as a feature in PBLSS, students have little experience in learning from their own work or in using their products to communicate with anyone but their teacher. Thus, while PBLSS included means for sharing with a broader community and for problem solving, most students remained teacher-centric with their representations. Since PBLSS was not adequately aligned with assessment (the representations made in PBLSS were not the representations graded), many students were not driven to use PBLSS enough for it to become a major part of their project work. It is unfortunately true that, in practice, a student's primary job in school is to find out what his or her teacher thinks is valuable and to achieve to that standard. Most students are well aware of this need. We see project-based learning helping almost all students rise above this schooling mentality during some parts of their project experience, but no one forgets that they are in school. It is clear that we need much better tools and processes for bringing teachers and students together around project work in order to overcome the inertia and tradition of classroom structures.

For technology to scaffold authentic inquiry in schools it must legitimately support and be aligned with both the teachers' interests in assessing student work, and the students' needs for support of the fluid and dynamic aspects of inquiry. Similarly, for students the role of the support system must grow with their understanding and appreciation for what it takes to do a project. At the beginning of a project, students understand less, so they may need a free-form environment with some markers to give them direction. As students grow in understanding of their projects and the work of doing projects, they should be able to select the tools and structures that best fit their needs. These tool sets and structures should sufficiently support both the authentic inquiry required by their projects and the outcomes or representations required of their enrollment in classes. Our efforts to scaffold more effective learning and performance have helped us to see that although there is great benefit in structuring the learning environment so as to help students select the appropriate next step in their work, our design also needs to adapt to the learner's prior experience and comfort level in taking that step. Before accepting a structure or method, both teachers and students must trust that the system has been designed with their goals in mind, and that it will be both efficient and effective in helping them meet those goals.

Do PBLSS and the Project MOST assessment and learning opportunities use technology to effectively scaffold authentic inquiry in school environments? We believe the answer is yes, or perhaps yes, almost. We believe that the next steps forward in our project are: (a) to better support the daily work activities of the students, and (b) to create a better fit between PBLSS and the assessment methodology in place in our Project MOST schools.

CONCLUSIONS

The teachers involved in Project MOST believe that bringing authentic, project-based learning to their students is necessary for meaningful learning to occur. Unfortunately, the very structure of schooling—the short periods for classes, isolated subject matters, and lone teachers in a classroom—hinder project-based learning efforts. Having students do meaningful projects is very challenging and nearly impossible to sustain in traditional schooling environments. Without new tools and structures to support new processes, it is unlikely that school reform of this magnitude will succeed.

PBLSS is an attempt, through a collaborative design process with teachers and students, to develop tools and structures for doing projects that reduce the teacher's burden and that make student success more likely. Through cyclical design and revision efforts, PBLSS is becoming a valuable software system. Much remains to be done, however, and we are challenged to find ever better technological solutions to the requirements of doing authentic projects in schools. As with any support system, the eventual success of PBLSS will depend on how much value it provides to our teachers and students in the context of doing projects within the schooling structure. Advancing the PBLSS architecture will provide an environment for studying authentic learning, the processes of doing projects, and the structures needed for their support. □

James Laffey and Dale Musser are Co-Directors and Thomas Tupper is a Research Scientist of the Center for Technology Innovations in Education at the University of Missouri-Columbia. John Wedman is Director of the School of Information Science and learning Technologies at the University of Missouri-Columbia.

Correspondence regarding this article should be addressed to James Laffey, Center for Technology Innovations in Education, 111 London Hall, University of Missouri-Columbia, Columbia, MO. 65211; phone (573) 882-5399; e-mail jim@coe.missouri.edu.

REFERENCES

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

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

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

Collins, A. (1996). Design issues for learning environments. In S. Vosniadou, E. De Corte, R. Glaser, & H. Mandl (Eds.), *International perspectives on the design of technology supported learning environments* (pp. 347–362). Hillsdale, NJ: Lawrence Erlbaum Associates.

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

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

Dewey, J. (1933). *How we think: A restatement of the relation of thinking to thė educative process.* Boston: Heath.

Dewey, J. (1938). *Experience and education.* New York: Macmillan.

Geertz, C. (1983). *Local knowledge.* New York: Basic Books.

Gery, G. (1991). *Electronic performance support systems.* Boston: Weingarten.

Hawkins, J. (1995). Supporting teachers in changing roles. A group paper from the NSF Educational Technology Workshop. *Setting an agenda for computer science in educational technology* (pp.23–31). Washington, D.C.: Computing Research Association.

Jackson, S.L., Stratford, S.J., Krajcik, J., & Soloway, E. (1995). A learner-centered tool for students building models. *Communications of the ACM, 39*(4), 48–49.

Krajcik, J., Blumenfeld, P., Marx, R., & Soloway, E. (1994). A collaborative model for helping middle grade science teachers learn project-based instruction. *The Elementary School Journal, 94*(5), 483–497.

Laffey, J. (1995a) Project MOST: Building a new educational community to support project-based learning using the internet. *Proceedings of AACE World Conference on Education Multimedia and Hypermedia.* Association for the Advancement of Computing in Education.

Laffey, J. (1995b). Dynamism in electronic performance support systems. *Performance Improvement Quarterly, 8*(1), 31–46.

National Research Council, (1996). *National Science Educational Standards.* Washington, D.C.: National Academy Press.

Norman (1993). *Things that make us smart: Defending human attributes in the age of the machine.* Reading, MA: Addison-Wesley Publishing Company.

Perkins, D.N. (1993). Person-plus: A distributed view of thinking and learning. In G. Salomon (Ed.), *Distributed cognitions: Psychological and educational considerations* (pp. 88–110). Cambridge, MA: Cambridge University Press.

Resnick, L.B. (1987). Learning in school and out. *Educational Researcher,* 16(9), 13–20.

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

Schön, Donald (1983). *The reflective practitioner: How professionals think in action.* New York: Basic Books.

Spitulnik, J., Struder, S., Finkel, E., Gustafson, E., Laczko, J., & Soloway, 1995. *Toward supporting learners participating in scientifically-informed community discourse.* Paper presented at the Computer Support for Collaborative Learning Conference, Bloomington, IN: Indiana University. October 1995.

Vygotsky, L.S. (1978). *Mind in society: The development of higher psychological processes.* Cambridge MA: Cambridge University Press.

Wiggins, G.P. (1993). Assessment: Authenticity, context, and validity. *Phi Delta Kappan,* November, 200–214.