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Motivating Project-Based Learning: Sustaining the Doing, Supporting the Learning

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Project-based learning is a comprehensive approach to classroom teaching and learning that is designed to engage students in investigation of authentic problems. In this article, we present an argument for why projects have the potential to help people learn; indicate factors in project design that affect motivation and thought; examine difficulties that students and teachers may encounter with projects; and describe how technology can support students and teachers as they work on projects, so that motivation and thought are sustained.

How can I motivate children? How can I get children to think about what they are doing, not just focus on getting it done? How can I get children to really understand the material, not just pass tests? These are age-old and important questions of educators and continue to be central issues in psychological research. Motivational questions are often studied in isolation from questions of thinking and learning; however, the job of the teacher requires an integration of these two related, but often disparate, areas of study. If one of the important goals of schooling is to foster the development of students' minds by engaging them in sophisticated and substantial opportunities for deep understanding of curricular content, then educators must concern themselves with motivational questions that examine how students engage in and persist at such activities.

In searching for organizing principles of instruction and curriculum that

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attend to critical relations between motivation and thinking, researchers have recurringly turned to the idea of projects: relatively long-term, problem-focused, and meaningful units of instruction that integrate concepts from a number of disciplines or fields of study. In this article, we present an argument for why projects have the potential to help people learn; indicate factors in project design that affect motivation and thought; examine difficulties that students and teachers may encounter with projects; and describe how technology can support students and teachers as they work on projects, so that motivation and thought are sustained.

Within the last decade, a considerable body of empirical research and theory has shown the link between student motivational orientation and cognitive engagement in schoolwork (Ames & Archer, 1988; Dweck & Elliot, 1983; Harter, 1983; Meece, Blumenfeld, & Hoyle, 1988; Nolen, 1988; Pintrich & De Groot, 1990; Pokay & Blumenfeld, 1990; Winne & Marx, 1989). Several sets of goal orientations have been proposed: mastery versus ability, learning versus performance, and task versus ego involvement. Each set of goals differs primarily in terms of whether learning is perceived and valued as an end in itself or as a means to external ends such as grades, gaining approval, or avoiding negative evaluation by others. Students who adopt goals characteristic of the first of each of the pairs are motivated to learn (Brophy, 1983). Such students try to benefit from school assignments and demonstrate greater levels of cognitive engagement in schoolwork, and they report using more self-regulation, cognitive, and metacognitive strategies. Use of such strategies is related to the development of deeper level understanding of subject content (Weinstein & Mayer, 1986; Wittrock, 1986).

In addition to stressing the importance of learning strategies, recent work on learning emphasizes the critical role played by tasks and the environment. Previous work on tasks suggests that they serve as critical links among student motivation, student cognition, instruction, and learning (Bennett, DesForges, Cockburn, & Wilkinson, 1984; Blumenfeld, Mergendoller, & Swarthout, 1987; Doyle, 1983; Marx & Walsh, 1988). In fact, tasks have been described as the basic instructional unit in classrooms. Those who have characterized instructional tasks express dismay about the focus on low-level facts and skills and the omnipresence of worksheets in American classrooms (e.g., C. W. Anderson & Smith, 1987; Brophy & Alleman, 1991; Doyle, 1983; Goodlad, 1983; Sizer, 1984). Students are afforded few opportunities to represent knowledge in a variety of ways, pose and solve real problems, or use their knowledge to create artifacts.[1]

[1]We use the term artifacts to *denote* sharable and critiquable externalization of students' cognitive work in classrooms. In contrast to the use of the word in other fields, our use of the term is synonymous with *product*. However, we use *artifact* to denote that the results of

The prevalence of low-level tasks contributes to students' lack of understanding of content and process and poor attitudes toward learning and schooling.

The introduction of more cognitively complex tasks, which provide opportunities for solving real problems, often is urged as a remedy for this situation. Drawing analogies from everyday learning, researchers argue that knowledge is contextualized; that is, learners construct knowledge by solving complex problems in situations in which they use cognitive tools, multiple sources of information, and other individuals as resources (Brown, Collins, & Duguid, 1989; Resnick, 1987). Moreover, because learning occurs in a social context, learners interact with and internalize modes of knowing and thinking represented and practiced in a community (Toulmin, 1972). The master–apprentice relationship is used as an analogy for the teaching–learning situation. It is argued that, 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. The result of such an approach to teaching is that learners are motivated to persist at authentic problems, meld prior knowledge and experience with new learning, and develop rich domain-specific knowledge and thinking strategies to apply to real-world problems.

PROJECT-BASED LEARNING AS MOTIVATIONAL

An integrative perspective on motivation and learning has led to new interest in student projects. Project-based learning is a comprehensive perspective focused on teaching by engaging students in investigation. Within this framework, students pursue solutions to nontrivial problems by asking and refining questions, debating ideas, making predictions, designing plans and/or experiments, collecting and analyzing data, drawing conclusions, communicating their ideas and findings to others, asking new questions, and creating artifacts.

There are two essential components of projects: They require a question or problem that serves to organize and drive activities; and these activities result in a series of artifacts, or products, that culminate in a final product that addresses the driving question. Students can be responsible for the creation of both the question and the activities, as well as the nature of the artifacts. In addition, teachers or curriculum developers can create questions and activities. However, in neither case can the question be so

student's cognitive work proceed through intermediate phases and are continuously subject to revision and improvement.

constrained that the outcomes are predetermined, leaving students with little room to develop their own approaches to answering the question. Students' freedom to generate artifacts is critical, because it is through this process of generation that students construct their knowledge—the doing and the learning are inextricable. Artifacts are representations of the students' problem solutions that reflect emergent states of knowledge. Because artifacts are concrete and explicit (e.g., a model, report, videotape, or computer program) they can be shared and critiqued. This allows others to provide feedback and permits learners to reflect on and extend their emergent knowledge and revise their artifacts.

Projects are decidedly different from conventional activities that are designed to help students learn information in the absence of a driving question. Such conventional activities might relate to each other and help students learn curricular content, but, without the presence of a driving question, they do not hold the same promise that learning will occur as do activities orchestrated in the service of an important intellectual purpose (e.g., Sizer, 1984). Proponents of project-based learning claim that as students investigate and seek resolutions to problems, they acquire an understanding of key principles and concepts. Project-based learning also places students in realistic, contextualized problem-solving environments. In so doing, projects can serve to build bridges between phenomena in the classroom and real-life experiences; the questions and answers that arise in their daily enterprise are given value and are shown to be open to systematic inquiry. Hence, project-based education requires active engagement of students' effort over an extended period of time. Project-based learning also promotes links among subject matter disciplines and presents an expanded, rather than narrow, view of subject matter. Finally, projects are adaptable to different types of learners and learning situations.

Examples of published projects include those produced by the Technical Education Research Center and the National Geographic Society on science topics including acid rain and solar energy. These particular projects focus on important environmental problems (although there is no reason why projects need to focus on applied issues); involve students in data gathering and analysis; examine local industry and laws; and make use of new technologies, including microcomputer packages and telecommunications, with which students can gain information as well as share their findings with others outside the classroom. Similar projects built on a smaller scale can be developed by classroom teachers or teams of teachers. Whether the project is developed by publishers, teachers, or students, activities associated with these projects should be designed to be interesting and meaningful to learners and promote a deep level understanding of the content.

PROBLEMS WITH PROJECT-BASED LEARNING AND SOURCES OF SOLUTIONS

There is a richness to a good project that can be exploited by teachers and students. Projects can increase student interest because they involve students in solving authentic problems, in working with others, and in building real solutions (artifacts). Projects have the potential to enhance deep understanding because students need to acquire and apply information, concepts, and principles, and they have the potential to improve competence in thinking (learning and metacognition) because students need to formulate plans, track progress, and evaluate solutions.

Despite considerable potential, project-based education is not without problems. The idea that projects represent learning by doing certainly is not new. Roots of this conception go back to Dewey. However, lessons from the past suggest that without adequate attention to ways of supporting teachers and students, these innovative educational approaches will not be widely adopted. Previous attempts at reform of curriculum and instruction in the 1960s used "hands-on" and discovery learning as central themes. Although evidence suggests that such curricula enhanced student learning and motivation (e.g., Bredderman, 1983), their adoption was not as widespread as desired. Many reasons can be advanced for this. We submit that the projects were developed and disseminated without sufficient appreciation for the complex nature of student motivation and knowledge required to engage in cognitively difficult work. Furthermore, there was little regard for considering questions from the point of view of students (as distinguished from experts). Finally, little attention was paid to the nature and extent of teacher knowledge and commitment and the complexity of classroom organization.

The newer cognitively based approaches that contemporary projects represent also require substantial changes in teachers' thinking about and dispositions toward classroom structures, activities, and tasks. These changes, as previous curriculum innovations have demonstrated, are not easy to achieve. A quarter of a century of research and development has suggested that innovation in curriculum and instructional practice requires that considerable attention be paid to curricular content and organization, psychological factors associated with learners (e.g., individual and developmental differences in use of knowledge, motivational orientation, cognitive strategies, and metacognition), and professional practice issues of teachers (e.g., teacher efficacy, opportunities for professional development with colleagues, and organizational time and support for teacher reflection). In order to realize the potential of project-based instruction, projects must be designed that sustain student motivation and thoughtfulness and teachers must be supported in creating this type of instruction. Close attention, then, must be given to the design of project questions and associated activities and to strategies to improve teachers' implementation of projects.

One of the major educational developments in the past quarter of a century that has potential for fostering project-based education is the creation and expansion of new educational technology tools that can support students and teachers in obtaining, analyzing, and sharing information and constructing artifacts. Technological power is advancing rapidly. Prices are falling, making sophisticated options affordable for schools. Technology has the potential to sustain student motivation and support student learning and doing during the various phases of projects. It can support teachers in similar ways. Technology can supplement and complement teachers' instructional and managerial roles, relieving teachers of some of the complexities of implementing projects. It also can help sustain teacher involvement in project-based education by enhancing their knowledge and professional competence.

In the next sections, we review work on students' motivation and learning, teachers, and technology. We discuss what prior research has established, describe some of the work under way by our group and others, and note the problems that need to be addressed in developing and implementing project-based education.

THE ROLE OF PROJECT DESIGN IN ENHANCING MOTIVATION AND FOSTERING COGNITIVE ENGAGEMENT

To benefit from project-based instruction, students need to be cognitively engaged with subject matter over an extended period of time. Advocates of a focus on complex tasks as an important component of classroom instruction assume that students will be motivated to test their ideas and deepen their understanding when confronted by authentic problems in a situation that is similar to how learning occurs in out-of-school settings. Unfortunately, evidence indicates that students do not necessarily respond to high-level tasks with increased use of learning strategies (C. W. Anderson & Roth, 1989; Blumenfeld & Meece, 1988; Winne & Marx, 1982). Students often are resistant to tasks that involve high-level cognitive processing and try to simplify the demands of the situation through negotiation (Doyle, 1983; Stake & Easley, 1978). Although students may be interested in the topic and possess relevant knowledge and procedures for solving problems or mastering new material, they do not necessarily use these strategies (Paris, Lipson, & Wixson, 1983; Winne & Marx, 1982). It is insufficient merely to provide students with opportunities designed to promote knowledge that is integrated, dynamic, and generative, if students will not invest the effort necessary to acquire information, generate and test solutions, and evaluate their findings. Also, complex high-level activities are often implemented by teachers in a manner that reduces the need for student thought (e.g., Blumenfeld, in press; Doyle, 1983). Consequently, project-based education is not likely to work unless projects are designed in such a way that, with teacher support, they marshal, generate, and sustain student motivation and thoughtfulness.

A number of factors should be considered in project design that affect whether students will be motivated to do projects in a manner that fosters understanding. These factors include whether students find the project to be interesting and valuable, whether they perceive that they have the competence to engage in and complete the project, and whether they focus on learning rather than on outcomes and grades. Although there certainly are individual differences that influence what students find interesting and valuable (Dweck & Elliot, 1983; Harter, 1983; Meece et al., 1988; Nicholls, Patashnick, & Nolen, 1985; Pintrich & De Groot, 1990), we can explore how projects might be designed to increase the likelihood that most students will be motivated by them. We shall review elements of project design that are likely to affect interest and value, perceived and achieved competence, and task focus, and we raise questions for research on these elements.

Interest and Value

The interest and value students attribute to the problem and elements in projects will affect how motivated they will be to engage in the project. Student interest and perceived value are enhanced when (a) tasks are varied and include novel elements; (b) the problem is authentic and has value; (c) the problem is challenging; (d) there is closure, so that an artifact is created; (e) there is choice about what and/or how work is done; and (f) there are opportunities to work with others (Malone & Lepper, 1987). Each of these factors, and how it should be considered in designing projects, is discussed next.

With respect to variety and novelty, there is danger that interest may be heightened at the expense of cognitive engagement. Students may get hooked by dramatic or unique elements in tasks, but such characteristics may not sustain motivation and cognitive engagement over the extended time needed for project-based learning. Instructional activities that resemble entertainment programming on commercial television, might suggest to learners that the medium requires passive rather than active cognitive engagement (Salomon, 1983). In addition, too many "bells and whistles" may deflect focus from the main idea, resulting in confusion among learners regarding the intellectual focus of activities (Winne & Marx, 1982).

Although interest and value are likely to be enhanced by pursuing authentic questions to which students can relate, such as topics dealing with personal health and welfare, community concerns, or current events, we have little systematic empirical information about what problems students actually find valuable, interesting, or useful enough to work on for long periods. Teachers and curriculum designers can gain information from students' leisure pursuits, but integrating these with academic subject matter remains problematic. In particular, a crucial issue is how to ensure that the project questions are educationally rich enough that in seeking answers students must gain understanding of significant subject matter concepts.

Tasks that have closure and that entail the production of authentic artifacts are more likely to sustain interest. Nevertheless, how to create conditions in which the questions students pursue and the artifacts they produce are not "school-like" remains an issue (Malone & Lepper, 1987). Projects also need to be feasible and manageable given the time and resources available to students and teachers (see Brophy & Alleman, 1991). Moreover, artifacts should be rich enough to promote both depth and breadth of knowledge in their creation as well as demonstrate student mastery of the content. The importance of the nature of the artifact cannot be overstated. Artifacts need to require the student to integrate information and use complex thought. If students pursue a problem that promotes complex learning and thinking, but design an artifact that is trivial, the potential benefits of project-based learning are not likely to accrue.

Concerning finding an optimal level of challenge, students are often willing to exert what they consider to be reasonable effort to gain success (Brophy, 1983). However, as the task becomes more difficult or time consuming, students may focus simply on completing the work with minimum effort rather than engaging demanding strategies to try to understand it. Thus, questions remain about how to promote effort and persistence over the extended time necessary to complete projects. Likely areas for research include goal setting, providing opportunities for feedback to encourage continuing work, and building social norms for group work.

A number of researchers (e.g., Deci & Ryan, 1987; Lepper, 1988) have argued that choice and control are critical to enhance motivation to work on classroom tasks. Project design can allow students to exercise choice and control regarding what to work on, how to work, and what products to generate. For instance, students can (a) select project questions, activities, and artifacts; (b) determine how to approach the problem, what steps to follow, what resources to use, and how to allocate responsibility; and (c) choose the artifacts to construct and how to construct them. Balancing students' need for choice and control in the selection of problem questions, approaches, and artifacts so that they feel "ownership" with the need to have students address and learn content defined by curricular mandates and requirements poses a significant dilemma. Moreover, questions abound regarding optimal proportioning of choice and control between teachers and students so that novices are not overwhelmed by the demands of doing projects and select artifacts that facilitate the development and demonstration of subject matter understanding.

A cornerstone of the newer approaches to learning is collaboration with students in the same classroom and in classrooms located at other sites. Carefully designed cooperative learning programs have been shown to enhance student achievement and attitudes (e.g., Bossert, 1989; Cohen, 1986; Slavin, 1983). However, group work can diminish thoughtfulness by encouraging reliance on others as resources, thereby decreasing personal responsibility and independent thinking (Corno & Mandinach, 1983). Blumenfeld (in press) found that students reported more motivation to learn but less use of learning and metacognitive strategies during small-group work. The learning effectiveness of such organizational arrangements depends largely on the types of problems posed, the way groups are composed, and the ways in which students are held accountable for their learning (Good, McCaslin, & Reyes, in press; Slavin, 1983; Webb, 1982). Moreover, although they may find the situation enjoyable, students may not have the skills to benefit from collaborative work. Working with others requires that students be able to discuss ideas, communicate clearly, consider alternatives systematically, monitor their own understanding, compare their point of view with that of others, and ask clear questions. Such self-directed learning requires considerable cognitive and metacognitive sophistication. Whether students have such sophistication, and how we can help them develop or use it to enhance collaborative learning is of central importance (cf. Eichinger, Anderson, Palincsar, & David, 1991).

We have discussed in this section features of project design that are likely to influence student motivation and raised questions that can serve as a research agenda. Questions about features likely to affect interest and value include the following: What projects that entail important subject matter content will students find interesting, challenging, and valuable enough to work on for long periods? What individual differences are likely to influence the ways in which students approach tasks and the resources that they can bring to bear on their work? How do students' self-perceptions of ability and their interests in particular subject areas influence their persistence at difficult tasks as well as their willingness to defer to others when the level of challenge exceeds their capacity to respond? How can we balance students' choice and control over selection of the subject, the approach to the problem, and the artifacts generated while at the same time providing enough structure so that novices won't be overwhelmed? How can we use collaborative work and ensure productive interaction among students?

Perceived and Achieved Competence

In doing projects, students need access to information and examples or representations that will help them to understand and use central ideas. They also need to use tool skills that are necessary to undertake the project (e.g., reading maps, using a compass, or operating computer software). Students need to use an array of learning, metacognitive, and problem-solving strategies during projects. Moreover, they need to keep track of the process and components, because they are likely to go through several iterations of these processes to improve their work. Finally, they need to see errors and false steps as learning opportunities rather than as indicators of low ability.

Given these requirements, several factors may affect students' perceived and actual competence as they engage in complex projects. First, students need to have sufficient knowledge of the content and specific skills to explore information pertinent to the problem. Students often have considerable gaps in their knowledge or hold initial preconceptions of fields like mathematics and science that are quite resistant to change. These may interfere with their ability to understand or benefit from information accessed during project-based learning activities (e.g., Confrey, 1990; Driver & Oldham, 1986).

Second, as we describe in detail in the section entitled The Role of Technology, students need to be proficient at using cognitive tools like computers and accompanying software programs. In any long-term complicated endeavor like project-based learning, students may become discouraged or frustrated if they lack the necessary knowledge and skills, the problem becomes too complex, or the solution is too difficult to determine or demonstrate. The cognitive tools afforded by new technology should help support complex learning. However, technology will not be appropriated by students as tools if they believe it is of limited usefulness or too difficult to learn.

Third, students need to be proficient in using cognitive and metacognitive skills to generate plans, systematically make and test predictions, interpret evidence in light of those predictions, and determine solutions. According to Winne and Marx (1990), the elements of these cognitive skills include storing information in memory, monitoring progress toward goals, assembling units of information into larger schemas, rehearsing newly consolidated learning, and translating information from one form of representation to another (e.g., visual to verbal or mathematical to linguistic).

Cognitive skills such as these enable students to manage complexity. As the number of ideas to consider or the number of procedures that need to be followed increases, students may need to stay organized, track their progress, and maintain a focus on the problem rather than get confused by its elements. For instance, studies of laboratory work in science (Hofstein & Lunetta, 1982) suggest that students often concentrate more on figuring out how to cope with the procedures than on what they are supposed to learn.

There are at least two types of metacognition that are employed in project-based learning. One is tactical, relating to the moment-to-moment control and regulation of cognition. The other is strategic and concerns more molar levels of control over larger units of thought. These two features of metacognition refer to different types of knowledge about academic tasks. Tactical control represents students' ability to monitor and fine tune thought as they work through the details of particular tasks. This type of cognitive control enables students to remain focused on the goals of the activity while they struggle through the hard work of creating intermediate artifacts. Students who have inadequate tactical control are likely to have difficulty sustaining mental effort in the moment-to-moment work of generating artifacts. Strategic control represents students' ability to engage in purposeful thought over what might seem to be disconnected elements of projects. In project-based learning, students need to be far more responsible for guiding and controlling their own activities and focusing their work on creation of their artifacts over a long period of time. The capability of students to organize their mental effort in the service to these long term purposes depends on strategic metacognition.

Fourth, students' perceptions of the role of errors in fostering learning need to be considered. Errors are detrimental to learning when they are construed as representing failure to learn. But when they are perceived as attempts to make meaning and to solve difficult and demanding problems, then errors signal just those cognitive and motivational efforts that are desirable for project-based education. In fact, errors are a natural and inevitable consequence of working on potentially ambiguous and ambitious tasks. In this vein, Rohrkemper and Corno (1988) argued that learning to deal with errors is adaptive and can contribute to academic success. Thus, a redefinition of error making is central to success with projects; teachers and students who conceive of errors only as failure to learn will have extraordinary difficulties succeeding at project-based learning.

Project-based learning requires considerable content and metacognitive knowledge on the part of students as they work on extended and potentially ambiguous activities. Even if they think they can successfully complete the task, students are likely to become frustrated and fail to persist or engage cognitively with the material if they cannot do the task. It is imperative that project design and implementation take account of the difficulties discussed in this section in order to support students' cognitive competence, contribute to their success, and thus sustain their perceived competence.

Questions about features likely to affect perceived competence include the following: How should students' prior knowledge be considered when designing projects and activities for representing key ideas so that students will be able to understand the material and develop competence? How should projects be designed to encourage the use of cognitive and metacognitive skills to develop learning skills and metacognitive abilities? How can projects be designed to help students maintain mastery goals, take risks, and view errors as a natural part of learning in situations in which evaluation and grades are inherent? Obviously, features of project design are not the only factors that will affect student motivation; teachers play a considerable part in whether students will be interested in and believe themselves capable of doing projects. Therefore, we discuss in the next section how teachers can contribute to student motivation and problems teachers may encounter.

Task Focus

Classroom conditions will affect whether students adopt learning or performance goals in doing projects. Even if they are interested in the problem and perceive themselves to be competent to carry out the project, students may not engage the topic in a manner that promotes understanding if the teacher makes performance orientations salient. Performance, rather than learning, orientations are more likely when teachers emphasize grades and comparative performance, discourage risk taking, use evaluation criteria that stress right answers, enforce accountability for work by imposing externally controlling events such as rewards and punishments, or assign primarily low-level tasks. There are many things teachers can do to promote adoption of "mastery" goals (see Maehr & Midgley, this issue). Nevertheless, even in supportive classroom environments, projects still can create anxieties for students that are difficult to dispel. Given the realities of the performance–grade exchange and the fact that tasks such as those in projects are complex and inherently ambiguous and risky (see Doyle, 1983), students are likely to worry about evaluation and may be quite uncertain about what counts as an acceptable artifact.

THE ROLE OF TEACHERS IN ENHANCING MOTIVATION AND FOSTERING COGNITIVE ENGAGEMENT

In project-based education, as in traditional instruction, teachers need to (a) create opportunities for learning by providing access to information; (b) support learning by scaffolding instruction and modeling and guiding students to make tasks more manageable; (c) encourage students to use learning and metacognitive processes; and (d) assess progress, diagnose problems, provide feedback, and evaluate overall results. In addition, teachers need to create an environment conducive to constructive inquiry and manage the classroom to ensure that work is accomplished in an orderly and efficient fashion. In project-based instruction, these issues become more problematic because of the ambiguity of project-based learning, and the likelihood that numerous activities will occur simultaneously, therefore changing classroom management routines and participant structures.

Even well-designed projects cannot sustain student motivation themselves; teachers play a critical role. A central issue is to determine how teachers can help students work through projects in a manner that sustains motivation and thought. No less important is how we can motivate teachers to create and implement project-based learning. Like students, teachers need to feel competent and value what they are doing in order to be willing to engage in new forms of instruction.

Currently, a great deal of research is being conducted to determine how teachers can best fulfill these roles. Earlier studies focused primarily on how teachers could present information effectively (e.g., Rosenshine & Stevens, 1986) or directly teach learning and thinking skills (Rosenshine, 1987; Weinstein & Mayer, 1986). This knowledge transmission model of teaching has given way to a knowledge transformation conception of teaching. A more contemporary question concerns how teachers can help students examine and expand their own ideas to develop flexible and meaningful understanding of subject matter and modes of thought. Research in the fields of mathematics, science, social studies, and literacy provides models of how such instruction can be accomplished (see Brophy, 1989).

Motivation research also has implications for teacher practices. The focus has moved from concentrating on individual differences to examining how the classroom environment and teacher practices affect the learning goals that students adopt (Ames & Archer, 1988; Corno & Rohrkemper, 1985; Meece, Blumenfeld, & Puro, 1989). Teachers can create environments that promote motivation to learn and encourage inquiry, risk taking, and thoughtfulness by minimizing ability-related information and focusing on learning, not performance. This work has shown that motivation and instruction are intertwined; creating motivation to learn by enhancing interest and value does not necessarily translate into greater cognitive engagement unless teachers also employ instructional practices that press for active learning on the part of students and hold students accountable for understanding (Blumenfeld, in press; Blumenfeld, Puro, & Mergendoller, in press).

Nevertheless, teachers need a great deal of support in carrying out these roles. It is likely that many teachers will have difficulty fulfilling these functions because of their knowledge and beliefs about learning and teaching; instruction that relies heavily on textbooks and worksheet drill and practice; classroom management routines that are based on lock-step scheduling and whole-class activities; and assessment and accountability practices that focus on fact retention, are highly public, and require competitive reward systems. We review some of the problems likely to be encountered before detailing how technology can support students and teachers. We argue that it is not only the student's motivation that must be sustained, but also the teacher's.

Teachers' Content Knowledge, Pedagogical Content Knowledge, and Beliefs

Project-based instruction affords exciting opportunities for teachers and students to explore problems in depth and to draw on concepts across subjects. However, these opportunities assume that teachers possess knowledge of content included in projects, understand how to explain or illustrate content and teach learning strategies, and hold belief systems compatible with a constructivist approach to teaching and learning. These requirements are not easily met.

Like their students, some teachers hold alternative or incomplete conceptions of subject matter (Krajcik & Layman, 1989; Smith & Neale, 1989). Their knowledge of the concepts and the process skills addressed by a project may not be sufficient to enable them to distill the concepts the project addresses, identify possible links between the central ideas in the project and other concepts in the subject area covered in the curriculum, or recognize ways other disciplines can be incorporated into projects. One issue in doing projects is how to help teachers understand project content to enable them to help students.

Teachers may have sufficient understanding of the concepts, but may not have pedagogical content knowledge of probable alternatives; possible misconceptions of students; or activities, explanations, demonstrations, and analogies that can provide powerful illustrations of the concepts (Shulman, 1986). Also, they may not be adept at modeling thinking and problem-solving strategies or scaffolding instruction in ways that progressively release responsibilities to students.

Teachers' beliefs regarding their role, the goals of schooling, and how students learn are frequently antithetical to the assumptions underlying project-based instructional approaches (L. Anderson, 1989). Teachers often view learning as a process of obtaining information rather than an active process of knowledge construction; they often view motivation simply as a problem of developing positive attitudes rather than enhancing cognitive engagement. Thus, they often select tasks with the goal of providing something interesting for students to do and give less attention to achieving cognitive goals, integrating material with prior learning, or considering how the artifacts that students generate influence their thinking and learning (Clark & Peterson, 1986; Shavelson & Stern, 1981; Winne & Marx, 1987).

Instruction. To successfully implement project-based instruction, teachers need to help students become aware of and examine their own conceptions, and develop and use learning strategies. Research over the last decade has identified instructional strategies such as predictions (Lewis & Linn, 1989) and discrepant events (Nussbaum & Novick, 1982; Osborne & Freyberg, 1985) that help make student understanding more explicit. Considerable research in classrooms indicates that carrying out this type of instruction is difficult. Even if teachers are sympathetic to such an approach, many are more comfortable and familiar with lecture and recitation situations and tend to stress right answers over hypothesis generation, prediction, data collection, and analysis. Moreover, to benefit from project-based instruction, students need to have considerable skill in using learning, problem-solving, and metacognitive strategies. Thus, scaffolding is especially critical for students who are not proficient in using thinking strategies. Teachers themselves need models and support in learning how to help students learn.

Assessment. Project-based instruction requires that teachers be able to ascertain what students know about the problem before beginning the project, their level of understanding during execution of the project, and what they learn as a result. The typical standardized test or workbook question focuses primarily on low-level comprehension and is inappropriate for examining short- and long-term benefits of project-based instruction. Examples of informal measures that can provide guidance and feedback for both teachers and students are journal or notebook entries, portfolio assessment, clinical interviews, and examining student discourse. However, teachers need help in using such techniques to diagnose student understanding because they are less structured, more clinical, and more time consuming.

Management. Project-based instruction engages children in high-level and complex learning activities that often have no right answer or one way to be accomplished. This type of academic work is difficult for teachers to manage and sustain (Blumenfeld et al., 1987; Doyle, 1983, 1986; Stake & Easley, 1978; Tobin & Capie, 1988). High-level cognitive tasks are associated with lower completion and higher error rates; these factors slow the momentum of a lesson, increase student need for help, and heighten the potential for disorder. As a result, teachers often feel pressured to simplify material or suspend accountability for learning under these circumstances (Doyle, Sanford, Clements, French, & Emmer, 1983). If teachers capitulate to these pressures when using project-based instruction, many of the putative motivational and learning benefits will not materialize.

Classroom environment. Project-based instruction relies on a classroom climate that promotes inquiry and a mastery orientation. However, many classrooms promote performance rather than a mastery orientation to learning. Teachers in the former type of classrooms stress correct answers, grades, competition, and public comparison with others (Ames & Archer, 1988). Consequently, students are less likely to take risks, worry more about errors, and make less use of cognitive and metacognitive learning strategies to obtain greater understanding.

THE ROLE OF TECHNOLOGY

Technology can play a powerful role in enhancing student and teacher motivation to do projects and in helping students and teachers implement projects. In this section we describe how technology can contribute to student motivation to do projects by enhancing interest and, more important, supporting learning and the production of artifacts by making information accessible. The aim is to show how technology can share some of the teacher's responsibility for helping students as they engage in project-based learning. We also describe how technology can help inform teachers about project-based learning and aid in project implementation. Finally, in recognition that technology, like all educational innovations, is not without its problems, we raise issues for future research.

Technology and Students

Enhancing interest. Technology can contribute to how interesting and valuable students find projects. Students are more likely to take part in project-based learning when projects focus on questions that they perceive as valuable, are challenging, include a variety of activities, are realistic, allow interaction with others, and result in authentic products. Technology can enhance challenge, variety, and choice by providing multiple levels of tasks to match student knowledge and proficiency, access to numerous sources of information that allow breadth in project questions, and offer many possibilities for artifact production. Moreover, tasks may be perceived as more authentic by students because the computer can access real data, can expand interaction and collaboration with others via networks, and emulate tool use by experts to produce artifacts.

Although there certainly are individual differences in its appeal, observational research (Cognition and Technology Group, 1990) suggests that technology can make a project more interesting. In studying the Geometry Tutor, Kafai (1989) observed that students preferred computer-based over noncomputer-based geometry instruction and asked for additional problems to solve using the Proof Tutor. Similarly, Scardamalia, Bereiter, McLean, Swallow, and Woodruff (1989) showed how student control of learning and immediacy of feedback influenced student motivation to work on difficult tasks with computers. Moreover, Malone and Lepper (1987) found that computer activities motivated students because they allowed for control, were interactive, provided immediate results, and allowed for different levels of challenge.

Access to information. In the process of doing projects, students need access to information about key ideas, concepts, and subject matter topics that might arise. Technology makes information more accessible. Traditionally, teachers and books have been key sources of information. Consulting other sources such as archives or references like the *Reader's Guide to Periodical Literature* is, at minimum, time consuming and sometimes is not possible, depending on the student's geographical location or available resources. Electronic data bases allow learners access to massive amounts of information that are easily obtainable while sitting at a personal computer. The information can be either static, such as electronic encyclopedias or historical records, or live, such as transmissions from weather satellites. Similarly, networks and various forms of teleconferencing "expand the classroom walls," providing access to peers and experts in other locations. For example, the National Geographic Society's KidsNet network (Tinker & Papert, 1989) provides the opportunity for upper elementary students to gather local data on the pH of rain water. Through the use of networks, students discuss their findings with scientists and share results with those collected by students in other locations.

Obviously, simply providing access to information does not guarantee that it will be useful to the students. A central issue is how to design and organize these information sources to be profitable to students. Progress is being made on ways to structure information systems to be more useful to students working on authentic tasks. For example, Scardamalia and Bereiter (1991) studied methods to structure computer-based discussions of writing among peers, such as providing prompts and starting sentences for critiques.

Active representation. The multimodal and multimedia capabilities of technology not only enhance the physical accessibility of the information, but also facilitate its intellectual accessibility. In addition to text, there has been an explosive growth in the use of media—sound, graphs, color pictures, and even video—on the computer. This variety provides for representation of single concepts in multiple, simultaneous modalities. These multiple representations can enhance student understanding. For example, Kozma, Russell, Johnston, and Dershimer (1991) explored representation of chemistry concepts via video, animation, and textual mathematics equations simultaneously on a single screen.

Technology also allows students to manipulate and construct their own representations easily and to do so in several media. Harel and Papert (1990) noted significant increases in mathematics learning among their students who devised various graphical and textual representations of fractions using Logo programs. Simulations and microworlds, such as those developed by diSessa (1982) and White and Horwitz (1987), allow students to explore and manipulate ideas actively in artificial environments that minimize extraneous detail and make it easier to note interactions between the available variables. Similarly, microcomputer-based laboratories (MBL) allow students to collect real-time data: Students can ask "what if" questions, use electronic sensors to test their predictions, and view the results of these experiments in various forms like graphs or charts (Friedler, Nachmias, & Linn, 1990; Linn, Songer, Lewis, & Stern, 1991; Mokros & Tinker, 1987). Finally, some data base systems provide facilities for students to organize and create their own indices; the process of navigating through and organizing the information can help students to create their own mental representations of that information.

Because technology allows students to explore, construct, and easily alter representations, as well as control the process, motivation is likely to be affected positively. Computers respond quickly, and the cost of change is relatively minimal. Once students are familiar with software applications and the power and versatility that they provide, they may be more willing to explore alternatives actively and take more risks. Thus, the motivational qualities of computers as cognitive tools are likely to be enhanced when software has been well learned and its use is relatively automatic. When students have developed competence with software, mental effort can be devoted to the intellectual task of creating artifacts, not to the details of production. Consequently, students' engagement can be more "mindful" (Salomon, Perkins, & Globerson, 1991), and the potential of project-based learning can be realized.

Structuring the process: Providing tactical and strategic support. The opportunity to view, manipulate, and create multiple representations using technology does not ensure that students will take advantage of these capabilities in a manner that enhances understanding. Students need to use cognitive and metacognitive strategies as they gather, manipulate, and integrate information and as they work through the phases of a project—setting goals, planning, monitoring and evaluating progress, and producing and revising artifacts. Although the teacher serves a critical role in guiding students and modeling learning processes, a focus of considerable study is how to design the technology itself to promote what Salomon and Globerson (1987) termed "mindfulness."

Whereas early applications of technology emphasized specific skill acquisition, as in computer-assisted instruction (Suppes, 1980), more recent applications emphasize the learning of process. Technology can be designed to provide tactical and strategic support. Tactical support can be provided by prompts that suggest the learner use a particular operation or ask for articulations or explanations. For example, Linn et al. (1991) used prompts in an MBL environment to encourage students to make predictions and to compare their results with their predictions after the experiment. These prompts can serve as cognitive aids in learning. At a macro level, software can be designed to offer both strategic and tactical support. Such programs guide the learner to be systematic and to use coherent routes in problem solving. The intent is to place students on a trajectory toward gaining an expertlike process. For example, Soloway (1991a) developed the GoalPlanCode Editor, which structures the process of writing PASCAL programs. To encourage greater expertise in students' processes, the software requires students to decompose problems into pieces and to articulate goals for a piece before writing a code.

Technology also can be designed to provide strategic support by specifying and explaining steps the learner should follow. For instance, CSILE (Computer-Supported Intentional Learning Environments), a program for supporting text composition, provides icons that suggest stages of process development such as indicating cognitive goals, plans for pursuing them, and target dates (Scardamalia et al., 1989). Similarly, INQUIRE (Brunner, Hawkins, Mann, & Moller, 1990; Hawkins & Pea, 1987) structures the process of developing research questions by providing both explicit process representation and detail-level prompting.

Another strength of technology is that levels of tactical and strategic support can be graduated to accommodate differences among individuals in knowledge of content and process necessary for projects. Supports also can accommodate individual change as a student's knowledge of the content and process develops across time. Soloway (1991a) examined how to design software in order to fade scaffolds. In a related vein, they also have experimented with approaches that allow learners themselves to alter the degree of scaffolding.

Diagnosing and correcting errors. Because of the complexity of project-based learning, errors can be made over a wide range of processes and content. Indeed, errors and false starts are an inherent part of doing projects. Students need to evaluate thinking about the problem, their solution, and their products. That is, they need to diagnose and correct errors in specific parts of the project, in the process that was followed, or in the artifacts produced. Technological support for locating errors can be provided directly via explicit statements of where errors occurred and how to correct them or more indirectly by guiding the student's review with suggestions that vary in specificity (e.g., J. R. Anderson, Boyle, & Reiser, 1985). Moreover, programs like INQUIRE that provide explicit support for reflection on the process can indirectly help students identify difficulties in the steps they followed.

Although making errors is an inevitable part of project-based learning, the cost is not the same for all types of errors. When students make errors in tactical components of project work, it is likely that technology can help convert the error from an indicator of inability to a sign of progress toward successful construction of artifacts. Once tactical errors are diagnosed, technology makes change easy. Because the cost of change is cheap, students can explore alternative solutions without undue expense. For example, Nachmias and Linn (1987) found that students learning to interpret graphs through MBL equipment recognized inaccurate or flawed graphs more easily than did students who did not learn with technological support. They suggested that the students who used MBL equipment were able to generate graphs more quickly and thus were able to explore a range of both good and bad graphical representations.

Not all errors, however, are easy to change. Rectifying fundamental strategic errors might involve considerably more cost to the student. For example, students who have invested considerable time and energy to produce an MBL representation of an artifact might have considerable difficulty interpreting errors as cheap. Such work might entail significant amounts of time and cognitive work to search data bases, videodisks, and text in order to construct an artifact. If the wrong data bases were selected, or if visuals on a videodisk were inaccurate representations of concepts and principles, then students might be far less willing to revise material in order to improve the quality of final artifacts. This issue might have considerable impact on students' motivation to sustain work on projects.

Managing complexity and aiding production. Students who are working on projects produce a range of intermediate and final artifacts. As already mentioned, artifacts are significant as externalizations of the student's understanding because they can be shared and critiqued. The computer can help students generate artifacts by minimizing physical and mental detail. Application software such as word processors, spreadsheets, desktop publishing programs, and drawing programs automate the generation of attractive illustrations and meaningful graphs and compute complex series of equations. New programs being developed (Guzdial & Soloway, 1991; Pea, Boyle, & de Vogel, 1990; Soloway, 1991b) allow students to manipulate video, text, graphics, and animations to develop multimedia compositions and presentations. Automation of the details of production frees the student to explore greater levels of complexity in the content of the project and the design of artifacts. Obviously, however, if using the application is complicated or too demanding, the student is less likely to invest the time in mastering the tool and thus will not benefit from its possibilities.

Summary. Technology affords considerable potential for motivating students to carry out projects. We have detailed ways in which it can contribute both directly by increasing students' interest and value and indirectly by aiding the teacher in supporting students as they gather information relevant to project questions and use that information to generate artifacts that represent their understanding. How technology can best be designed to serve these functions remains to be determined. Many questions remain: How much support should be provided? Is there a danger of "de-skilling" students because they rely heavily on the technology? How can supports be built into a program to be used by a range of students, from the complete novice to the relative expert? How do we ensure that students use these supports, and continue to use them? How do we make error correction easy, but still thoughtful? How can the experiences on the computer be structured so that learning is transferred (Salomon et al., 1991)? It is important to note that, for the most part, these questions are not unique to technology but apply to traditional instruction as well.

A critical issue, we believe, is that technology supplements but cannot supplant the teacher in helping students do projects. Moreover, its contribution depends considerably on the culture and norms the teacher creates, within which technology is used and whether it is employed as an integral tool in project execution. Therefore, a key research issue is how to promote this interplay between teacher and technology in facilitating projects and to determine what roles are appropriate for the teacher to assume and what roles are appropriate for technology. Other concerns are how to help teachers use the technology to learn about and implement projects and help them exploit technology's benefits for students. We consider these issues next.

Technology and Teachers

We have described possibilities for how technology can share some of the teacher's role in sustaining student motivation in project-based learning.

Instituting project-based learning can be rewarding for teachers; however, because of the new and unfamiliar demands it creates, it can also be problematic. The implementation of project-based learning is a complex and multifaceted endeavor. There is likely to be a considerable gap between existing practices and practices called for in project-based education. Technology can play a role in supporting teachers as they learn about and implement projects in the classroom. Specifically, teachers need to know about (a) project content and powerful ways to illustrate that content, (b) project-based instruction (e.g., how to help students plan, carry out, and evaluate their work), (c) management of project-based learning, and (d) adaptation or generation of projects in light of their students' specific needs.

Research on teaching and teacher development suggests how technological material can support teachers as they think about and cope with the problems they are likely to face in doing projects. These approaches (for a review, see Clark & Peterson, 1986) view teaching as a highly complex cognitive activity, in which diverse sources of knowledge must be integrated. These perspectives focus on the teacher as a reflective professional (Schon, 1983), in contrast to the previous emphasis on skills and techniques. Key elements in these approaches are the teacher's thinking, decision making, planning, and reflection. Essentially, the view is that teaching involves learning; like their students, teachers construct their knowledge of subject content, pedagogical content, curriculum, and students and draw on this knowledge in designing instruction (Shulman, 1986, 1987). Project support materials should not only enhance the teacher's knowledge base about projects but also aid in the planning process. In addition, the materials should not be prescriptive. Instead, they should focus on ways to help teachers create a set of experiences by adapting existing projects or generating new ones in light of their particular teaching circumstances and students. The materials should allow teachers to access information about projects in a variety of ways.

To address such needs, we are building a Project Support Environment (PSE) for teachers that provides information about these areas. In particular, the PSE will be a hypermedia information system that will enable teachers to see actual videotapes of implementation of project-based learning on the computer; it will enable them to access information about content and instructional issues from a concrete (e.g., how to help students make predictions) and more theoretical perspective (what factors promote thoughtfulness). It includes a tool that allows teachers to construct plans and networking capabilities to facilitate communications among teachers. Because the PSE is a constructive tool, it provides access to information from many different points. In the following sections, we briefly describe how a system like the one we envision can contribute to teachers' implementation of project-based learning.

Content and pedagogical content knowledge. Like their students, teachers can benefit from the information access, multiple representation, multimedia, and networking capabilities of technology. Via networks, teachers can get information about the central ideas and concepts in projects as well as the numerous incidental questions that are likely to arise. Their understanding is likely to be both broadened and deepened because they can see information represented in a variety of ways and also use the technology to manipulate and create their own representations. For example, Krajcik, Layman, Starr, and Magnusson (1991) used technology to enhance teachers' knowledge of temperature and heat energy concepts.

Technology can also help improve teachers' pedagogical content knowledge. Methods of helping students understand ideas or concepts (which activities, explanations, and analogies teachers have tried that worked or did not work) as well as information about possible student misconceptions or alternative conceptions can be stored in a hypermedia system, illustrated visually, and shared among teachers through networks. For instance, instructional examples might be shown to teachers who ask, "How can I explain motion?" Currently, teachers are limited to suggestions in manuals, their own experiences, or conversations with colleagues. Technology offers an exciting opportunity for vastly expanding the source of teachers' information.

Instruction. Hypermedia information systems that combine text, video, animation, graphics, and audio can be developed in which teachers can see examples of how others have implemented projects. For instance, teachers can ask questions about how to encourage metacognition ("How can I help students generate and test predictions?"), about events ("How can I introduce projects?"), or about technology ("How can I use MBL to help students do what-if experiments?") and see video examples of how other teachers dealt with these questions. In addition, video clips can be annotated by the teachers pictured to include information regarding what they had intended to do and their reflections on what worked and what they would do differently the next time.

Planning and managing. Teachers will need to tailor existing projects or develop new projects to meet the specific needs and constraints of their classroom, school, and community. Also, they will need to develop plans for designing and implementing projects in their specific contexts. Technology can provide support for planning such design activity and for carrying out those plans. Moreover, these plans themselves are artifacts that can be shared with and critiqued by others and reflected on and revised by the teacher.

As part of the PSE, we have implemented and tested in the classroom a first version of such project-planning software, called IByD (Instruction By Design) with preservice teachers. The program is an expert shell that provides preservice teachers with strategic support for processes (developing goals, selecting activities, identifying evaluations, and describing possible instructional examples) and tactical support by requiring the user to provide rationales for choices and to show the plan's coherence by visually illustrating and explaining how elements of the plan are linked. Preliminary results (Blumenfeld, Soloway, Urdan, & Brade, 1991) suggest that IByD helped structure the process of planning so that the rationales of plans generated by computer users were significantly more systematic and explicit than those of the plans produced by non-computer-using subjects in the same teacher education course.

Summary. The technology teachers need to support their efforts at realizing effective project-based instruction corresponds to the technological tools that professionals in other areas routinely use (e.g., planning software, telecommunications software, and multimedia data bases). Although there is less consensus regarding whether teachers need such tools, few would argue against technological support for teachers that is commensurate with technological support in the commercial sector. We have argued that technology can directly support teachers as they learn about and implement projects and as they support student learning.

CONCLUSION

We have argued in this article that there is considerable promise in the notion of project-based education to enhance motivation and thought as students attempt to learn in classrooms. We have indicated factors in project design that are likely to affect motivation and thought, examined how teacher implementation of projects can influence motivation and thought, and described how technology can support students and teachers as they work on projects so that motivation and thought are sustained. Our main interest has been to examine motivational and instructional issues that need to be incorporated in attempts to research and implement project-based learning.

Projects in which students pursue long-term investigations of a significant question and produce artifacts that represent answers to those questions have the potential to motivate students and help them better understand subject matter content. The idea of project-based learning certainly is not new; however, considerable advances in our knowledge about motivation, learning, teachers, and classrooms increase the possibility of success now. Although there obviously will be individual differences in student reactions, projects can be designed to include elements that are likely to enhance most students' interest and value, including variety, challenge, choice, cooperation, and closure in the service of answering real questions. In addition, by considering students' prior knowledge and thinking skills, projects can be designed to support students so that they feel able to succeed.

Although research and theory have provided answers to many important questions related to implementing project-based education, we need to know a great deal more about how to sustain student motivation and thought in projects. Project-based learning requires considerable knowledge, effort, persistence, and self-regulation on the part of students; they need to device plans, gather information, evaluate both the findings and their approach, and generate and revise artifacts. Such requirements are not easily met. Teachers will play a critical role in helping students in this process, by shaping opportunities for learning, guiding students' thinking, and helping them construct new understandings. However, project-based learning is likely to pose difficulties for teachers too. They may need help with content, with new instructional forms, and with implementation and management of projects.

We argue that technology can make substantial contributions to ameliorating these problems associated with project learning. It can enhance student interest because it can contribute to variety, challenge, interaction with others, and generation of artifacts. Technology can aid the teacher in achieving goals of project-based learning by making information more physically and intellectually accessible, guiding and promoting the use of learning strategies, and aiding in the production of artifacts. Moreover, it can support the teacher in learning about and successfully implementing projects. Although many questions remain about how to design and use technology effectively for these purposes, the fact that technology is becoming more powerful, available, and affordable makes determining how to utilize its power to motivate project-based learning in classrooms a timely and important endeavor for those seeking to improve education.

It is important to emphasize that project design, teaching, and use of technology all need to be considered as opportunities for marshalling existing student motivation, creating opportunities for motivation, and sustaining motivation once project-based learning activities are underway. Furthermore, we have argued that motivation and cognitive engagement are interative—one or the other becomes more or less salient during the course of project work. We have suggested potential questions that might help shape an agenda for research on learning and motivation in project-based education. Answers to such questions are likely to help guide the most recent wave of curriculum reform as educators address the problems that their predecessors faced and failed to solve.

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