A Case Study of Problem-Based Learning in a Middle School Science Classroom: Lessons Learned

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Abstract: Research on teacher thinking within a constructivist framework emphasizes the relationship between teacher beliefs about teaching and learning and effective classroom practices. A project sponsored by the EduTech Institute at Georgia Tech provides training and support to middle-school teachers using problem-based learning (PBL) in their science and math classes, seeking also to enhance the role of technology in learning. This report of an ethnographic case study in one 8th-grade science class discusses the specific difficulties encountered in implementing PBL and identifies coping strategies improvised by teacher and students in adapting to the unfamiliar roles and expectations of the PBL approach. Classroom observation and interviews with the teacher reveal the importance not only of training teachers in the appropriate classroom techniques but also of providing ongoing support as they develop context-sensitive PBL modules and acquire deeper understanding and acceptance of the philosophy underlying the new approach. Reflection infuses the teaching and learning processes, encouraging all participants to re-view both content knowledge and knowledge about learning.

In winter 1995, in response to the wishes of our primary funders and to numerous reports of disappointing student performance on assessments of science and math learning in this country, the EduTech Institute embarked on a project to enhance middle school science, math, and technology education. We formed a partnership with science, math and technology teachers from three local middle schools as well as with faculty members in science and engineering at Georgia Tech. The Tech professors bring up-to-date expertise in design, engineering and research; middle-school teachers provide content knowledge as well as their experience with students, the curriculum, teaching, and the classroom; and EduTech contributes expertise in the cognition of learning and problem solving, models of educational practice, assessment, and software design and development. Our goals are to help students understand the roles science and math play in the world, to offer classroom methods and technological assistance that will help them learn science and math more deeply and effectively, and to encourage more students to go into science and engineering careers.

Based on Georgia Tech's strengths and on what we know about learning, we decided to combine our goals by developing design problems for the curriculum that introduce students to technology and engineering while incorporating the math and science concepts that were already a part of the curriculum. These concepts would be situated in real-world problems whose relevance to students' own communities and lives would serve to motivate and contextualize learning. To support the endeavor, EduTech agreed to develop appropriate software as well. One research question we hope to address, as our study progresses, is whether such situated learning actually improves long-term retention of key concepts and problem-solving strategies, and whether those learned concepts and strategies are transferred to other problem situations.

RATIONALE FOR PROBLEM-BASED LEARNING

Recent curriculum development and teaching innovation in the math and science areas have taken a constructivist approach to education, one in which knowledge is seen to be the product of social interaction and situated within particular cultural and linguistic practices which influence the participants and the processes through which they construct knowledge (Cobb & Bauersfeld, 1995; Cobb, 1994; Driver et. al., 1994; Lemke, 1990). Teachers are increasingly encouraged to take the role of facilitator or coach rather than storekeeper of knowledge, and students are put into small collaborative groups where they are encouraged to share information, to relate new ideas to the world they inhabit, to ask questions, conduct investigations, and think critically about what they find. Journals of education are filled with articles about the theory and practice of inquiry, and many research studies have focused on aspects of problem-posing and problem-solving as a way to motivate and teach students about science and math (Helgeson, 1994).

Research also demonstrates the value of computer applications in enhancing the learning environment and improving student competence (Berger et. al., 1994). Our own approach to learning, drawn from case-based reasoning (Kolodner, 1993), supports the premise that effective learning is situated in complex problem-solving activity that reflects real-world needs and that draws on previously-acquired knowledge and experience to inform new understandings.

From this research on science and math education and teacher development, and from the extensive classroom experience of our teachers, we were able to formulate a set of central tenets which guide our work. These tenets include: (1) learning by solving complex realistic design problems; (2) integrating instruction in sciences, math, and technology; (3) integrating learning of concepts, skills, and critical thinking; (4) focusing on collaborative learning and doing; (5) fostering reflection and articulation to enhance learning; (6) software-realized scaffolding of collaboration, complex problem solving, and learning; and (7) providing on-line information resources and tools in an integrated software environment.

We found that the model of problem-based learning (PBL), developed by Howard Barrows (1985) for use in medical school classrooms, offered a methodology that was consonant with our principles of teaching and learning. In the PBL-based curriculum now used at numerous medical schools, students learn science by diagnosing patient case histories. Faced with ill-structured clinical problems, medical students work in small groups to summarize what they know, develop hypotheses, determine what they still need to find out, and plan their next steps. They next do independent research and then return to their groups to share information and continue with their analysis of the problem. Students are thus taught a methodology that scaffolds the solving of hard problems and promotes the acquisition of self-directed learning skills. The collaborative group format allows students to build on each others' strengths and knowledge and to gain needed experience in the skills of articulating and justifying their reasoning. Facilitators assigned to each work group help students to manage their collaborations, to stay on track in solving problems, and to reflect on their experiences in such a way that they appreciate the broad range of knowledge and skills they are acquiring and their applicability to other problems.

INITIAL PBL WORKSHOP FOR TEACHER AND CURRICULUM DEVELOPMENT

The goals of PBL correspond with the goals of our project and those of the teachers we are working with. During the summer of 1995 our partnership of teachers, professors and EduTech researchers met in a month-long workshop to explore the potential applications of PBL in middle-school classrooms and to design a number of trial curriculum modules to be implemented during the ensuing school year. Assisted by Paul and Joan Feltovich, experts from the Problem-Based Learning Institute in Springfield, Illinois, we organized training sessions for our teachers to help them learn how to carry out PBL methodology and to adapt it to the constraints of the middle-school classroom. Some of these constraints included the higher student-teacher ratio (often more than 30:1) in middle schools, issues of classroom discipline and control, use of collaborative learning and small-group techniques, support of parents and school boards, limited resources, and the social and cognitive development of young adolescents. Teachers were enthusiastic about the approach and worked hard to develop problems and compile suitable materials. They also had the opportunity to try out software tools being developed at EduTech to assist students in the scaffolding of problem-solving skills and to offer suggestions for the improvement of those tools.

However, after teachers returned to their classrooms in August, it became clear that they were not completely comfortable with carrying out PBL methodology. Most waited for several months or even longer before attempting to use the approach for even a short unit, and expressed uncertainty during the implementations about whether they were "doing it right" or whether students were responding satisfactorily. Teachers talked of their own uncertainty in the unfamiliar role of facilitator or coach, and struggled to balance the constructivist call for more student autonomy (and a concurrent decrease of teacher-centered direction and control) with the more familiar patterns of traditional didactic teaching. We also noticed that teachers were caught between their own familiar practices and beliefs on the one hand and their desire to cooperate with EduTech researchers in implementing new approaches and using new technologies on the other. We realized we would have to learn more about what it takes for teachers to institute change in their classroom practices to provide the support these teachers needed. To understand teachers' experiences, we decided to add a qualitative research component to the research effort originally aimed at measuring student success.

THE RESEARCH PLAN

A crucial aspect of the shift to PBL is to have teachers reflect on their own beliefs about classrooms and learning and to understand the philosophy of teaching that underlies the PBL approach. Recent research has explored the links between teachers' beliefs and attitudes and their adaptability to changing classroom conditions and methodologies (Calderhead, 1987; Clark, 1988; Floden & Klinzing, 1990; Schön, 1983; Shavelson & Stern, 1981, Sirotnik, 1983). Studies of teacher knowledge have identified two categories, pedagogical knowledge and content knowledge (Barnes, 1989; Shulman, 1987), showing that both kinds are essential to good teaching. Researchers have looked into the process of teacher change and the influence of teachers' backgrounds on the change process, finding that teachers are most likely to institute changes that are reasonably congruent with their preexisting beliefs and practices (Louden, 1991). Others have produced narrative studies of teachers' lives and their stories about teaching and learning (Elbaz, 1991; Goodson, 1992) to understand the effects of context on classroom practices. This constructivist approach views the teacher as an active agent for change and sees teaching as a creative, humanistic endeavor in which methods are adapted to suit particular settings, students and goals. Research within this paradigm has tended to be more qualitative and interdisciplinary, often involving observation in naturalistic settings and other ethnographic and ethnomethodological techniques (Louden, 1991; Rist, 1970; Spindler, 1982).

To better understand these processes of change, EduTech is conducting a series of qualitative studies of middle-school classrooms as teachers implement PBL modules. This paper reports on the first ethnographic case study involving one teacher, Ms. J, and her 8th-grade science classroom, as she uses "The Gold Problem." The problem was developed during the summer 1995 PBL workshop and modified by this teacher to augment an earlier unit on rocks and minerals that included a field trip to Dahlonega, the site of Georgia's own 19th-century gold rush. The report is based on field notes of daily participant observation in two classes throughout the 7-day unit, informal interviews with the teacher, and classroom artifacts. These data were coded following Glaser and Strauss' (1967) constant comparative method, and emerging categories revealed key focal areas of teacher and student concern. In this report we identify some of the issues teachers face as they implement this new classroom methodology. We discuss strategies improvised by both teacher and students to meet the unfamiliar demands of the PBL classroom, and from these we make a number of recommendations about how to facilitate teacher learning and development.

THE CLASSROOM SETTING

Ms. J is a veteran classroom practitioner, a conscientious and thoughtfully reflective educator who establishes her goals in advance, plans each class carefully, and keeps a journal to record notes about students, curriculum, activities, and teaching effects. She is not afraid of innovation and believes the best way to find out what is still needed in this PBL approach is to simply try it and see what happens. She is intrigued by the challenge of PBL and enthusiastic about the potential benefits of her partnership with the EduTech team, particularly the increased availability of technological support. Many of the features of PBL are already a part of this teacher's repertoire: she uses cooperative groups, encourages student independence and self-direction, is accomplished at guiding students through questions and suggestions rather than merely giving them information, has experience with alternative assessment measures, and is a skilled classroom manager. Her own interest in the subject matter is manifested in her enthusiasm for the topics at hand, and she conveys the clear impression that in this class serious work is both possible and expected. Ms. J treats students as respected co-investigators of indisputably fascinating fields of knowledge. There is no time to waste in her classroom: every minute is valuable, and students come to class expecting to work continuously.

The students in this suburban middle school are overwhelmingly white, middle-class teenagers, well-dressed, with no major learning disorders or social problems. Some are assigned to a special education pullout class, but their problems tend to be moderate, such as ADD and below-average reading or math ability. If they become inattentive or disruptive, they are responsive to the teacher's mild corrections, and all seem able to work independently.

Unfortunately the computer resources at this school are currently severely restricted due to temporary overcrowding, and consequently Ms. J is unable to gain access to the computer lab for the duration of the PBL unit. Internet access is also restricted as county administrators try to formulate a policy for use of the Internet by minors. It is thus not possible for this class to use the software being developed at EduTech, nor do they have in-school access to the vast resources of the Internet. However, many of the students have computers at home and use both the Internet and CD-rom encyclopedias to supplement the information available to them in class.

IMPLEMENTATION OF THE PBL MODULE

On the first day of the unit the students are presented with the problem statement:

> A thirteen-year-old boy in North Carolina recently found a sapphire worth $33,000. Georgia has riches too. "There's gold in them thar hills." And much of this gold is in the Atlanta area. Maybe we can get lucky too. Where might we find gold and what areas would be worth mining? You will make a presentation to potential investors.

Using the PBL "white board" format to brainstorm, the students make lists of FACTS (what we know), IDEAS (related thoughts and hypotheses), LEARNING ISSUES (what we need to know more about), and ACTIONS (what we need to do), recording the information on large sheets of poster paper tacked to the classroom wall. Once they have identified a number of items in each category, they begin independent research using materials the teacher has placed on a table at the front of the room. The teacher facilitates the brainstorming sessions to keep students focused and to guide them to resources that will answer their questions. She does not give prepared lectures about the content, nor does she attempt to provide structure to the unfolding information. Students discover and record pertinent facts as a result of their own exploration of the resources, and they discuss findings with group members to compile the evidence that will support their argument in the final group presentation. On the fourth day of the unit, Ms. J tries to stimulate students' thinking about the environmental impact of mining by introducing a lab experiment demonstrating the chemical process of reclaiming copper from a solution

However, as students work through the gold problem, a number of unanticipated difficulties in this initial application of the PBL approach become evident. In daily interviews, Ms. J talks of her frustrations. First, she is perplexed to find that several of her curricular objectives are not actually being addressed by the students' work. For example, she tells me that the "wording" of the problem statement leads students to focus on economic rather than environmental questions, and that the availability of mineral resource maps enables them to "find" the gold without having to learn about the geological processes that determine the types and locations of mineral deposits. Another problem is that the research materials she and the EduTech staff have gathered for students to use do not provide details about the geological processes, but instead steer students to consider mining techniques and legal issues. She feels that the content goals she identified in planning this unit have been replaced by tangential issues, and that the customary authority she has as teacher to redirect students' attention is not available in her role as PBL facilitator. She is uncomfortable with this loss of control, explaining that she is accustomed to "chunking off" bits of each topic so that students are introduced to concepts gradually and can build new knowledge on the old. "I need some more help or input with how to tier the problem, to find a way to make those two or three major facets of the problem more obvious," she says.

Her discomfort with the unintended direction of students' research leads her to abandon the PBL white boards, intended ideally as an ongoing record of student learning and reflection. She feels that the entries students made during the first brainstorming session were too far afield of her original goals for the gold problem, and so opts not to continue using the white boards because she "doesn't feel confident" in her facilitation of the problem and worries that students might get even further off-track. Her ambivalence about what she perceives as a surrender of control in the facilitator's role and her lack of confidence in students' ability to identify key issues create ambivalence in her commitment to what she calls "pure PBL." If time were not an issue, she says, the students might eventually arrive at the curricular goals on their own, but the current grading period is ending and a long list of county-defined topics remains to be covered during the school year. She chooses practicality over idealism when she asserts, "I may have to feed them more [information] than I should, but I will if I have to."

The students also encounter difficulties in coping with the PBL approach. The most noticeable issue is their initial level of uncertainty about the problem statement and what they are really expected to do. Though the teacher carefully explains the steps they will undertake, the scope of the problem and its open-endedness are daunting to these students who are accustomed to being given more explicit direction and less complex tasks. As a result, many students are either passive or openly resistant at various points through the unit. A second issue is that students do not see the problem as an authentic one, in part because they believe no adults would really consult them for advice about investments and in part because they have direct knowledge of the depletion of gold deposits in the geographic area. These eighth-graders have visited the abandoned gold mines in north Georgia and have heard their tour guide tell them there is not enough gold to warrant further efforts at extraction. Thus the gold problem is an exercise in fantasy, not a potential real-world puzzle, and their primary goal becomes to satisfy the teacher with the minimal effort required.

In addition, the small-group collaborations cause problems for many students. Though Ms. J felt that the

collaborative process worked well overall and that students seemed able to adjust to their group situations, there were numerous conflicts with the gathering, sharing, analysis and presentation of information, and also with interpersonal dynamics within groups. The students' general lack of research skills meant that they spent their time aimlessly flipping through pages of texts and journal reprints without knowing what information they were looking for, taking notes on easily recognizable data but failing to ask questions that would lead them to a deeper understanding of the issues. In addition, rather than dividing up research issues among group members, students tended to duplicate each other's work. Issues of gender and leadership also arose, with boys tending to push for decisions early in the process (often before doing much research) and girls assuming the passive role of group recorder. Finally, a number of groups had difficulty completing their assignment because of the uncooperative or inattentive behavior of one or two members who sabotaged the group's efforts. This is a problem Ms. J readily acknowledges and which she works hard to combat in the classroom by moving from group to group to encourage students throughout each class period and by frequently changing the composition of groups. Still, with thirty or more students packed into her small classroom, the task of maintaining order and concentration among these teenagers is intimidating. "It's really an art," she tells me, referring to the challenge of arranging groups to maximize cooperation and learning amongst the members.

TEACHER COPING STRATEGIES

Both teacher and students make adjustments in their expectations about the classroom and learning to cope with the demands of the PBL approach. Ms. J is a skilled teacher who uses many practices such as defining, clarifying, restating, reinforcing, summarizing and recapitulating information to guide students' learning. Yet she understands PBL to mean she should assume the less familiar role of facilitator, not provider of information, and encourage students to construct knowledge from their own investigations rather than from her condensation of text-based facts. As she attempts to take on this role, she improvises several techniques that might be helpful to other teachers as they try to direct student investigations and keep them moving forward in their research and analysis. These include:

Jump-starting: When students seem unable to move forward in their work, Ms. J offers a barrage of questions to stimulate their thinking. When she finds one group sitting passively rather than engaging with the resources, she sits down with them: "OK, How are you going to start?" she asks. They shrug listlessly. "What is the problem?" More shrugs. "Where might you find it?" One lifts the brainstorming handout tentatively. "What does it say? Read it," she encourages. She keeps up this rapid-fire questioning until the students in the group seem to discover a way to proceed, then leaves them to continue working on their own.

Check-ups: To keep students focused on the stages of their work, Ms. J checks to see if they're on-target for the schedule of activities. For example, when she finds several members of one group working on pictures for the presentation, she prompts them to remember the main goal of their collaboration: "Are you also thinking about making an argument?" she asks them. Seeing that one girl is making lists of facts, she continues, "Is that what B is doing? You need to put together the evidence to make a good argument, that's the meat of your presentation."

Dropping hints: The teacher mentions information and implies that it might be helpful to students. For example, when she wants students to notice some coincidences between geological regions and gold deposits, Ms. J introduces some maps included in the resource materials. "Here's one about geology occurrences in the West Central Piedmont," she tells them. "Where do we live?" (answer: the Piedmont.) "Yes," she confirms. "These might be useful to you."

Spotlighting: The teacher focuses on a previously unremarked aspect of some new information, or points out inherent conflicts in the facts students are developing. When a student finds an article staunchly opposed to mining, Ms. J asks who authored the article: it turns out to be a publication of the Sierra Club. "What is the Sierra Club?" she asks, and someone tells her it's an environmental group. "So you would expect them to oppose mining, wouldn't you, because of the harmful effects on the environment," she says. She suggests that they look for other articles by potentially pro-mining authors such as business leaders or politicians, and reminds them they must make up their own minds in weighing the evidence about what they believe.

Ratcheting up: Each day Ms. J recaps what they've done on the preceding day and sets a new challenge for them. For example, when the groups discover the mineral resource maps that show them exactly where gold is located in Georgia and where the mines are, several seem to feel that they've solved the problem: here's the gold, all we have to do is go get it. "Well, you have some good ideas about the first part of the problem, but so far you don't have any information about how to respond to the second part," she reminds them. She picks up some articles from the resource table and reads off the title and short summary of each one, suggesting ways to think about how the geographic information they've found might be connected to the issues raised in the articles. Then she leaves the students to

continue on their own.

Stepping back: This is a way of providing meta-structure for solving the problem, of reminding students of the "big picture" they're trying to address. As they begin work on the problem, she gets their attention for a moment to help them break the problem statement down into its parts: first, they have to find the gold; second, they have to decide whether it will be worth the effort to mine it; and third, they have to plan a presentation to a group of potential investors. She repeats this outline regularly each day to ensure that each group is addressing all three parts of the problem.

STUDENT COPING STRATEGIES

For their part, the students also encounter difficulties in adjusting to the PBL approach. Probably the most noticeable is their initial level of uncertainty about the problem statement and what they are really expected to do; another problem for students is to find ways to work with--or around--members of their collaborative groups. The following list describes some of their coping strategies:

Going through the motions: Experienced at following instructions and doing what they're told to do, a number of students doggedly work at taking notes. Some fill out the questions on the first-day task-sheet, and others make neat lists of facts without attempting to categorize or interpret them.

Doing what I'm good at: As the week goes on and the presentations become the focus of classroom activity, quite a number of students relax into the preparation of visuals for the group presentation, drawing pictures and making posters and signs. Though the teacher emphasizes that she will not count artwork in determining the quality of the group's argument, students obviously prefer this more familiar activity.

Passive non-participation: A few students simply do not take part in the work, disguising the fact by keeping papers in front of them. One girl makes multiple trips to the materials table to glance through articles, then returns to her seat empty-handed and chats until she notices that she's being observed, then returns to the materials table and repeats the process. A boy reads from a paperback copy of To Kill a Mockingbird that he keeps in his lap.

Giving up: Some students need a disproportionate amount of reassurance and "hand-holding," frequently raising their hands to ask for help. Because the teacher is usually busy with other students, they may sit for long minutes waiting for her to come over. If she doesn't come within 3-4 minutes, some of these students simply put their hands down and stare at the desktop, stymied.

Seizing control: In at least three groups, one student refuses to work cooperatively and seizes control by dominating the decision-making process. In each case the controller had done little or no research and analysis; each had instead jumped to a decision and then coerced his teammates into agreeing with him by bullying and ridiculing the opposition.

Bluffing and posturing: One student was particularly resistant to the work requirements of the problem. Though I never saw him actually read any of the articles, he always kept some resource material in front of him and, if an adult directed a question at him, he would invent a plausible response by glancing at the paper in front of him or drawing on his own background knowledge. His behavior serves as a reminder that students are experts in the types of behavior and discourse expected in the classroom, and many, like this boy, are able to bluff answers and pose as learners when in fact they have done no work.

Distracting others, off-task behavior: This final category of behavior was the most egregious, because not only would the offending student be off-task, but he or she would also prevent students in the vicinity from working. In effect, one student sabotages the efforts of the whole group, and sometimes of adjacent groups as well.

DISCUSSION

Teachers must make adjustments and find ways to integrate their own personal philosophy of teaching and style with any new teaching approach. In adopting the PBL approach, Ms. J has found this adjustment to be fairly unproblematic, in large part because the characteristics of PBL are consonant with her own practices as a teacher. Probably the two biggest changes for her under the PBL approach are, first, that she has to give up some of her customary control over which content to teach and when to teach it, and secondly, that she has to adjust to the PBL view of the teacher as facilitator and coach. Her conflicting beliefs about what's best and most efficient in the classroom are evident in some of her practices during this unit, including her decision to abandon the PBL white board format and her ambivalence about how much background information to give students when she introduces the PBL problems. She

also feels uncomfortable about the lack of structure available in the PBL format and feels constrained from refocusing students when they drift into curricular tangents. Yet she is intrigued by the interdisciplinary promise of the approach and eager to add the technological component as computers become more available to her students. She is anxious to give the white boards another chance and to incorporate more ongoing reflection into the PBL process during her next attempt; she now sees the white boards as a way to encourage in-progress adjustments in students' thinking, a potential solution to the structuring problem that concerns her rather than a fixed plan that misdirects student focus.

Ms. J's first experience with PBL has been one of growth and discovery for her pedagogically, expanding her own knowledge of teaching as her students explored content issues. Her example serves as a reminder to us at EduTech that teachers must be allowed time to grow into new teaching approaches, to try them on and make alterations so that the approach becomes a good fit with the teacher's own beliefs and practices. Teachers need support during this process: they need like-minded mentors and colleagues to talk with, for clarification and reassurance and renewed commitment; they need assistance with the details of planning and carrying out PBL units, such as designing curriculum-sensitive real-world problems and gathering materials appropriate to the abilities and interests of their students; and they need training in the skills of facilitation, collaboration and authentic assessment to help them move away from the tempting familiarity of traditional teacher-centered instruction.

Students also need time and support to adjust to the new ways of learning introduced by the PBL approach. Having been convinced through prior schooling practices that knowledge resides in texts and is filtered through teachers, they must now be persuaded that they possess both the ability and the authority to construct knowledge on their own using a full range of resources. They need research skills to know where and how to look for information. They need practice in skimming, looking for keywords, and cross-referencing. They must think critically--questioning and analyzing information and looking for potential bias in their sources. They need the skills and specialized language of collaboration, and to acknowledge the unique benefits of group diversity. As they gain confidence in solving complex problems, they learn to value the process of discovery. Finally, they learn to be responsible for their own education as they acquire the skills--and, we hope, the motivation--for lifelong learning.

As more of our teachers make use of PBL in their classrooms, we are collecting further data and broadening the scope of our research efforts. Using what we are learning in the classrooms to inform the design and functionality of our software, we are developing powerful computer programs that offer not only record-keeping capabilities but also provide for scaffolding of resource acquisition and use as well as the skills students need to explain and justify their arguments. We continue to explore ways to make technology more accessible to these classrooms so that teachers and students can take full advantage of, and provide feedback on, the software EduTech develops. We will add further case studies of classrooms and will augment the observation data with other measures of students' changing attitudes and learning about science and math. Our preliminary results have been encouraging, and we are eager to continue developing PBL curricula with our teachers. We believe that PBL is a promising methodology for the middle school classroom.

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