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

Alice Gertzman and Janet L. Kolodner
EduTech Institute
Georgia Institute of Technology
Atlanta, GA 30332-0280
{aliceg,jlk}@cc.gatech.edu

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 some of 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 expertise in using PBL 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. Such reflection must be supported as teachers are learning new classroom practices.

Introduction

In winter, 1995, in response to the wishes of our primary funders and to numerous reports about the low quality of science and math education in this country, the EduTech Institute embarked on a project to enhance middle school science, math, and technology education. We formed a partnership with nine teachers from three local schools and with science and engineering faculty at Georgia Tech. Faculty at Tech provide expertise in science, math, and technology; teachers provide expertise on students, the curriculum, teaching, and the classroom; and EduTech provides expertise in the cognition of learning and problem solving, models of educational practice, software design and development, and assessment. Our goals were to help students learn science and math more deeply and effectively, to help students understand the roles science and math play in the world, 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 address these goals in combination by developing design projects for the curriculum that introduce students to technology and engineering and provide them the opportunity to better learn math and science. In short, our proposal was that students learn science and math by working on engineering-related problems that require use of the math and science concepts that are already part of the curriculum. Parts of the curriculum would be covered by working on design problems, situating learning in realistic problem-solving activity. We would develop software to support the endeavor as well.

The central tenets guiding our effort come from cognitive science and educational technology research and the wisdom of teachers we are working with: (1) learning by solving complex realistic design problems; (2) integrating (as much as possible) education in sciences, math, and technology; (3) integrating learning of concepts, skills, and critical thinking; (4) focus 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 adopted problem-based learning (Barrows, 1985) as a classroom methodology. As an approach that situates learning in problem solving activity, it incorporates many of these principles and is consistent with our own approach to learning drawn from case-based reasoning (Kolodner, 1993). In problem-based learning, as done in medical schools, students learn science by solving authentic clinical problems. Together, they summarize what they know, what their hypotheses are, and what they still need to know; plan their next steps; and separately do whatever research is needed to continue solving the problem; coming back together when that research is done and continuing with their deliberations. Students are taught a methodology for going about solving problems that scaffolds the solving of hard problems and promotes the acquisition of self-directed learning skills. To enable students to successfully solve hard problems, they work in collaborative groups, where they can build on each others' strengths and knowledge. Working in collaborative groups also promotes learning how to articulate and justify; one cannot work successfully in groups without being able both to understand others and to make oneself clear to others. Facilitators assigned to each work group help students to manage their collaborations well, to stay on track in solving problems, and to reflect on their experiences in such a way that they learn the broad range of knowledge and skills that can be learned from these experiences.

The goals of PBL correspond with the goals of our project and those of the teachers we are working with. Over the summer of 1995, we organized training sessions for our teachers to help them learn how to carry out PBL methodology, and we worked together with them, with Georgia Tech faculty, and with experts on problem-based learning (Paul and Joan Feltovich) to develop problems appropriate for middle school and to adapt PBL to the constraints of the middle school classroom. With one teacher and thirty students, PBL small-group methodology is not possible, but our teachers decided that they could use large-group discussions to get students started in solving problems and for sharing between groups and have students work in small groups after large-group discussions had provided them with focus.

It became clear, after teachers returned to their classrooms in August, however, that they were not completely comfortable with carrying out PBL methodology. Most are now (in January) trying PBL or about to get started. They have become comfortable by trying out its pieces, first, on small problems that they were already familiar with and finding out that their students would respond. It became clear to us that if what we were developing were to have a broad impact, we would have to learn what it takes for teachers to become comfortable with the new roles they need to take on.

To better understand the processes of change that take place in middle-school classrooms when PBL is used, EduTech is conducting a series of qualitative studies of science and math teachers as they 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. We've identified some of the issues teachers must face as they implement this new classroom methodology and some of the ways students must adapt to the changes, and from those, we make some recommendations about how to facilitate teacher learning and development.

The Classroom

Ms. J is a veteran classroom practitioner, a conscientious and reflective educator who establishes her goals in advance, plans each class carefully, and keeps a journal to record thoughts 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 collaborative learning, 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, and is a skilled classroom manager. Her 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.

Classroom Implementation

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 in an abandoned mine. 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.

As a class, and 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 their thoughts both on large sheets of poster paper tacked to the classroom wall. After identifying a number of items in each category, they break off into small groups of 4-5 students, refine their lists, and begin independent research using materials the teacher has placed on a table at the front of the room. The teacher facilitates the large-group 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 structure the material presented. Students discover and record pertinent information through their own exploration of the resources, and they discuss findings with their group members to compile the growing list of evidence that will form the basis of their argument in the final group presentation. For this unit, students also perform a lab experiment demonstrating the chemical process of reclaiming copper from a solution, an activity Ms. J adds to get students thinking about the environmental impact of mining.

However, as students work through the gold problem, a number of unanticipated difficulties become evident. In daily interviews, Ms. J talks of her frustrations. First, she is perplexed that what she calls 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. Furthermore, the research materials she and the EduTech staff have gathered 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."[1]

The students also encounter difficulties with the PBL approach. The most noticeable issue is their initial uncertainty about the problem statement and what is expected of them. Though the teacher carefully explains the steps they will undertake, the open-endedness of the problem is daunting, and many students are either passive or openly resistant. An essential element of PBL is to "bring the problem home" to students, to make a connection with their real-world experience, but these eighth-graders have seen the abandoned gold mines in north Georgia and have heard their tour guide tell them there's 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. Virtually every group, for example, tediously copied lists of counties where gold has been found in Georgia, but none attempted to analyze the quantity or quality of this regional distribution of gold deposits. In addition, rather than dividing 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. In two groups, acrimonious disputes ensued when the boys dominated the discussion and forced the girls on the team to acquiesce to their preferred conclusion, despite a lack of solid evidence. 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. 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," Ms. J 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 as they learn 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 PBL asks her to 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, none of which are specifically part of the PBL approach, but all of which seem to enhance its use, at least in this classroom and with this beginning PBL teacher.

---

[1]A major problem here is that the problem did not correspond well enough to curriculum goals. This is an unfortunate, but necessary part, of developing problems for use in classrooms. It would seem that this problem might go away as problems are better developed, but we believe this issue will only show up in a different guise; as careful as we might be in putting problems and materials together, teachers will often have to adapt them for the idiosyncracies of their own curriculum guidelines and classroom environments.

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 working, 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 group seems ready to continue working on its 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 reminds them of their primary goal: "Are you also thinking about making an argument?" she asks them. 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. "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 so far and sets a new challenge. For example, when the groups discover mineral resource maps that show them exactly where Georgia's gold mines are located, 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 reads the titles and short summaries of several articles from the resource table, suggesting ways to think about how the geographic information they've found might be related.

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. At the beginning of each class, she reminds students to 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 several times over the course of the unit.

Student Coping Strategies

The students also encounter difficulties in adjusting to the PBL approach. Most noticeable is their initial level of uncertainty about the problem statement and what they are really expected to do; another problem is to find ways to work with --or around--members of their collaborative groups. The case study identified several coping strategies adopted by students, here omitted due to space constraints. Some help them move forward despite the frustrations; other strategies allow them to look busy without really participating.

Discussion and Conclusions

A critical need in effectively shifting from one teaching methodology to another is for teachers to reflect on their own beliefs about classrooms and learning and to understand the philosophy that underlies the new

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; Schon, 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. Louden (1991), in a classroom-based ethnography, found his teacher-subject to be most successful at instituting changes that were congruent with her pre-existing beliefs and practices. Narrative studies of teachers' lives and their stories about teaching and learning (Elbaz, 1991; Goodson, 1992) have explored the effects of background and context on classroom practices. The constructivist framework underlying these studies views the teacher as an active subject and agent for change whose teaching is a creative, humanistic endeavor, adapting methods to suit particular settings, students and goals (Louden, 1991; Rist, 1970; Spindler, 1982).

Teachers must make adjustments and find ways to integrate their own personal style and philosophy of teaching with any new approach. In adopting PBL, Ms. J has found this adjustment to be fairly unproblematic, in large part because the characteristics of PBL are consonant with her own teaching practices. Probably the two biggest changes for her under the PBL approach are, first, that she has to give up 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 boards 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 PBL 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 restructuring the problem student focus seems misdirected.

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 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. This initial analysis suggests several kinds of support that teachers need 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. Most importantly, they need support in learning to infuse the teaching and learning process with ongoing reflection, which leads to deeper understanding of both content knowledge and knowledge about teaching and learning and provides the key to retention and transfer of knowledge.

The study also suggests that students also need time and support as they adjust to the new ways of learning through PBL. 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 to learn research skills: where and how to look for information and how to figure out what information to look for. They need guidance as they learn to think critically; questioning and analyzing information and looking for potential bias in their sources does not come naturally. They need help acquiring the skills and specialized language of collaboration and learning to acknowledge the unique benefits of group diversity.

Learning all of this is probably not possible in one problem-solving session. Nor can it be "taught" prior to working on problems. Rather, the study suggests the necessity of giving students numerous opportunities to learn from problem-solving experiences, allowing them to learn these skills over time, by carrying them out and reflecting on them over numerous applications. As they gain confidence in solving complex problems, we hope they will learn, as medical PBL students do, to reflect on and value the process of discovery. This will lead, we hope, to students taking the initiative to hone their skills and will motivate and prepare them for

life-long learning. We are following up this study with others that shed more light on teacher development, on student development, and on adapting PBL-like methods for the constraints of middle school.

References

Barnes, H. (1989). Structuring knowledge for beginning teaching. In M. C. Reynolds (Ed.), *Knowledge base for the beginning teacher* (pp. 13-22). New York: Pergamon Press.

Barrows, H. S. (1985). *How to design a problem-based curriculum for the preclinical years*. NY: Springer.

Calderhead, J. (1987). *Exploring teachers' thinking.* London: Cassell Educational Limited.

Clark, C. M. (1988). Asking the right questions about teacher preparation: Contributions of research on teacher thinking. *Educational Researcher*, 17(2), 5-12.

Elbaz, F. (1991). Research on teacher's knowledge: The evolution of a discourse. *Journal of Curriculum Studies*, 23(1), 1-19.

Floden, R. E., & Klinzing, H. G. (1990). What can research on teacher thinking contribute to teacher preparation? A second opinion. *Educational Researcher*, 19(5), 15-20.

Goodson, I. F. (Ed.). (1992). *Studying teachers' lives*. New York: Teachers College Press.

Kolodner, J. L. (1993). *Case-Based Reasoning*. San Mateo, CA: Morgan Kaufmann.

Louden, W. (1991). *Understanding teaching: Continuity and change in teachers' knowledge*. New York: Teachers College Press.

Rist, R. C. (1970). Student social class and teacher expectations: The self-fulfilling prophecy in ghetto education. *Harvard Educational Review*, 40, 411-451.

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

Shavelson, R. J., & Stern, P. (1981). Research on teachers' pedagogical thoughts, judgments, decisions, and behavior. *Review of Educational Research*, 51, 455-498.

Shulman, L. S. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review*, 57(1), 1-22.

Sirotnik, K. (1983). What you see is what you get: Consistency, persistency, and mediocrity in classrooms. *Harvard Educational Review*, 55(1), 16-30.

Spindler, G. D. (Ed.) (1982). *Doing the ethnography of schooling: Educational anthropology in action.* New York: Holt, Rinehart and Winston.

Acknowledgements

This work was supported by the EduTech Institute through a grant from the Woodruff Foundation. Thanks to Joanne Collins for her willingness to be adventurous and for her help with the analysis.