Problem-Based Learning *for* Math & Science

Integrating Inquiry and the Internet

Second Edition

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Introduction

In the 1980s, the United States moved toward the consensus that its educational system needed to be reformed to meet the demands of an emerging information society—a society that required a workforce able to solve problems, apply knowledge, and reason analytically. To help today's students achieve success, teachers must be able to meet these evolving needs.

When subject areas are taught in a conventional school format, they are taken out of their natural context and presented to learners as independent and isolated units. Unfortunately, this traditional format operates in opposition to the brain's natural way of integrating and processing new information (Ronis, 2007). In mathematics classes especially, information has been taken out of context and is instead taught through the use of examples that show students how to solve problems, then ask students to complete large numbers of similar problems (Ronis, 2006). This process totally ignores the interpretations of current brain research as explained by educators such as Renate Caine, Geoffrey Caine, and C. McClintic (2002); Stanislas Dehaene (1997); Marion Diamond and J. Hopson (1998); Eric Jensen (2005); Robert Sylwester (2004); Pat Wolfe (2001); and James Zull (2002). The research appears to indicate that students (1) develop knowledge through interaction between themselves and the knowledge (active learning), (2) do not think like adults, and (3) learn extremely well through social interaction. When teachers disregard this information about how students actually learn mathematics and instead continue to reinforce drill and memorization, students' broader understanding of mathematical relationships and anything relating to mathematics in general can be harmed.

In the world outside the classroom, subject areas do not occur as separate encapsulated entities. Mathematics, for example, is an integral part of all science because it provides ways to quantify and record observations. Presenting learning and new knowledge in a separate and unconnected manner leads to a lack of student understanding regarding educational institutions and what they stand for. "Why do we need to learn this?" is a question veteran teachers have heard all too often.

The best way for teachers to equip learners with the skills and attitudes they need is through problem solving and inquiry learning (Stonewater, 2005).

Learning should involve the use of inadequately structured "messy" problems, problems that provide only a minimum amount of information—just enough to guide the investigation. These problems and situations cross subject boundaries and cannot predictably be solved using algorithms or formulas.

Inadequately structured, open, complex problems evolve as more information is gathered and often conclude with more than one solution. Student-directed inquiry serves as the heart of this problem-solving process. When students wrestle with the intricacies of such problems, they begin to discover what it is they need to know to arrive at an acceptable solution. Once in possession of this knowledge, they can then determine how to locate the information they need. This process allows students to learn to become effective and self-directed problem solvers and also to develop the ability to work collaboratively.

The problem-solving process has been expanded through technology that allows access to mathematics and science that could not be explored in the past. Theoretical mathematics models that could previously only be imagined can now be constructed using sophisticated software and computers. Difficult scientific models and experiments can be simulated in much the same manner. Technology helps create environments in which students can see changing relationships among variables and can engage in conjecture in a dynamic way. It allows students to tackle real problems with "messy" data and gives them control over different forms of representational relationships.

The workforce of the future will need a high level of technical skill: computers will continue to be used for tasks such as word processing, controlling machines, analyzing complicated sets of data, conducting research, and ensuring quality control in production processes. Current academic preparation in mathematics and science barely touches on these skill areas. As stated in the National Research Council report, *Mathematical Preparation of the Technical Workforce* (Mathematical Sciences Education Board, 1995):

> Mathematics in the workplace is quite different from mathematics in school. It is more concrete and more intuitive, yet at the same time more exciting and more unpredictable. It is rich in data and inextricably linked to technology. To become adults capable of thriving in the new workplace, students must be active learners and collaborative problem solvers. (p. 5)

As learners enrich the range of connections and relationships among different styles of absorbing, associating, and applying information, they form more intricate neural pathways in their brains, and concept retention increases. When learners are able to see otherwise abstract concepts functioning in their familiar world, a significant learning link is forged.

THE CONCEPTS EXPLORED IN THIS BOOK

This book examines the rationale behind inquiry and problem-based learning (PBL). Why is this exploratory method of learning so effective for mathematics and science education? How can problem-solving activities be made messier and brought closer to home so as to capture student interest and forge significant learning links? How might such learning be evaluated? And how might technology be made as much an integral part of education's inquiry process as it is currently part of real-world problem solving? This book also helps teachers design units that engage students in the exploration of important ideas, ideas that deepen understanding through their relevance and meaning to the learner.

PBL problems can vary widely as to the degree and level of teacher direction versus student direction. Starting with the greatest amount of teacher control and ending with the most student direction, the various types of PBL problems include:

- Teacher-directed PBL, in which the teacher selects the knowledge to be taught, creates the learning environment, develops and uses the evaluation materials, and presents the problem. This kind of PBL most resembles the traditional classroom.
- Real-life-referenced PBL, in which the problem evolves from an authentic situation, as in the environmental project presented in Chapter 4 of this book, The Mississippi Delta Dilemma.
- Simulation of a real problem, as in Chapter 3, where students are directed to create their own roller coasters and bridges.
- Student-community problems, where PBL can facilitate students' learning how to conduct a real-life decision, as in the car project discussed in Chapter 6, in which students decide which car to buy after gathering information from local car dealerships and banks.

THE STANDARDS USED IN THIS BOOK

The standards used for the projects in this book are based on standards from the National Council of Teachers of Mathematics *Principles and Standards for School Mathematics* (NCTM, 2000), the National Science Education Standards (NSES), the International Society for Technology in Education (ISTE), and the National Education Technology Standards (NETS) Project. Each project starts with a list of relevant standards related to the age group targeted for that project.

The intent of the mathematics, science, and technology standards can be expressed in a single phrase: mathematics, science, and technology standards for all students. An educational paradigm shift toward these standards is urgent, due to the manner in which society has recently evolved. Commerce now functions in a worldwide arena filled with fierce international competition, while technology has become an essential part of people's daily lives. In spite of the excitement and innovation that has accompanied this dynamic state of affairs, the current educational system in the United States remains under attack for its lack of substance and relevancy (*Trends in International Mathematics and Science Study* [TIMSS], 2003). Educators, policymakers, parents, and the community at large are asking themselves, "Just how are we failing our children?" By using a standards guideline, a collective outlook can be formed as to what quality education looks like, today and in the future. The current standards movement offers a coherent vision for the future, defining excellence for performance as well as content standards in the various subject areas. These standards apply to all students, regardless of age, gender, cultural or ethnic background, disabilities, aspirations, and intent and motivation.

Standards-based instructional policies are essential for the evolution of the current educational system. Traditionally, new concepts have been presented as disconnected fragments that create an inherently inconsistent curriculum through which students study a series of isolated ideas. What is now known about learning demonstrates that if these new concepts are not in some way connected to previously learned concepts, they cannot become enduring or meaningful to the learners (Caine & Caine, 1997a, 1997b). Standards help connect learned concepts to new concepts by building a bridge between what is known and what is to be learned.

The NSES (science) standards integrated throughout this book state that teachers of science should do the following:

- Plan an inquiry-based program for their students
- Guide and facilitate their students' learning
- Engage in ongoing assessment
- Design and manage learning environments that provide students with the time, space, and resources needed for learning science
- Develop communities of science learners that reflect the intellectual rigor of scientific inquiry and the attitudes and social values conducive to science learning

The International Society for Technology in Education, an organization committed to addressing the development and application of knowledge through its National Educational Technology Standards Project, lists technology foundation standards that are reflected throughout this book. These include the following:

- Technology as productivity tools
- Technology as communication tools
- Technology as research tools
- Technology as problem-solving and decision-making tools

The NCTM standards for mathematics from *Principles and Standards for School Mathematics* (2000) stress problem solving as a meaningful method of inquiry and application. This is principally due to the following:

- Problem solving is the process by which students experience the power and usefulness of mathematics in the world around them.

- Problem solving can establish a "need to know" and foster motivation for development of the concepts.

- A balance must be established between problems that apply mathematics to the real world and problems that arise from the investigation of mathematical ideas.

• Computers and calculators, as powerful problem-solving tools, can help students become independent doers of mathematics.

• The nonroutine problem situations envisioned are different from traditional word problems, which provide contexts for using particular formulas and/or algorithms, but do not offer opportunities for problem solving.

• Students need to work together frequently in small groups to discuss strategies and solutions, ask questions, examine consequences and alternatives, and reflect on the process and how it relates to prior problems.

While students achieve understanding in diverse ways and at various levels according to their interests and abilities, all students can develop the knowledge and skills described in the various standards. In fact, some students will achieve well beyond those levels.

Mathematics, science, and technology standards rest on the premise that learning is an active process. Learning mathematics and science is something students do, not something that is done to them, and technology provides the tools for students to learn. Hands-on activities, while essential, are not enough in and of themselves. What students really need to ensure their success is "minds-on" experience.

THE GOAL OF THIS BOOK

This book is intended for educators interested in strengthening student understanding and comprehension in the fields of mathematics and science. The use of technology skills and tools as well as the creation of new instructional models and designs are the keys to accomplishing this goal.

The book does not suggest that all instruction be constantly geared toward deep and sophisticated understanding. There are many instances (such as the mastering of multiplication facts or chemistry element symbols) where such depth is neither desirable nor feasible. Rather, this book is about the understanding that once those basic skills have become a part of the learner's vocabulary, a more sophisticated understanding of the subject can be achieved only through direct participation in meaningful inquiry and discovery. Traditional teaching methods are not to be discarded, but PBL should be used to enhance, strengthen, and expand the educator's repertoire to increase student success.

Each of the six chapters in this book outlines an aspect of PBL as it relates to math and science. At the end of the chapters, projects designed to engage learners in the PBL experience are provided. Each project opens with a list of the project standards as they relate to math, science, and technology covered in the project, and also includes the information, student handouts, and evaluation forms necessary for completion. These projects can be modified to suit various learning levels.

The ideas and concepts of PBL are explored in each chapter in the following ways:

- Chapter 1 explores the concept of an integrated, inquiry-based approach to mathematics and science, and discusses why these subjects should be taught in this manner, how technology provides the glue for this learning, and how teachers can best use such exploratory methods in the classroom. The chapter closes with a multilevel meteorology project.

- Chapter 2 explains why problem-based (inquiry) learning is relevant and how it relates to current brain research on how students learn best. This chapter also includes a multilevel entrepreneurial project.

- Chapter 3 discusses ways in which PBL can be implemented to synthesize mathematics, science, and technology and make them more creative, relevant, and global. Two secondary-level projects dealing with real-world mathematics and physics are also offered.

- Chapter 4 provides strategies for implementing PBL in the math and science classroom and offers a multilevel environmental project.

- Chapter 5 offers information on alternative assessment and evaluation measures. Samples of different rubrics are provided as well as sample self-evaluations and reflections for both group and individual work. This chapter contains a multilevel practical applications project dealing with architectural design.

- Chapter 6 introduces the concept of community-embedded mathematics and science activities, offers ways teachers can engage the community as a learning resource, and explains how such activities can be initiated as well as integrated into classroom learning. In this chapter, the multilevel project gives students the opportunity to interact with the local business community.