CONTENTS

PREFACE

In science education, there are numerous strategies designed to promote learners' ability to apply science understanding to authentic situations and build connections between concepts (Bybee, Powell, and Trowbridge 2008). Problem-based learning (PBL; Delisle 1997; Gijbels et al. 2005; Torp and Sage 2002) is one of these strategies. PBL originated as a teaching model in medical schools (Barrows 1986; Schmidt 1983) and is relevant for a wide variety of subjects. Science education, in particular, lends itself to the PBL structure because of the many authentic problems that reflect concepts included in state science standards and the *Next Generation Science Standards* (*NGSS*; NGSS Lead States 2013).

The Problem-Based Learning Framework

PBL is a teaching strategy built on a constructivist epistemology (Savery and Duffy 1995) that presents learners with authentic and rich, but incompletely defined, scenarios. These "problems" represent science as it appears in the real world, giving learners a reason to collaborate with others to analyze the problem, ask questions, pose hypotheses, identify information needed to solve the problem, and find information through literature searches and scientific investigations. The analysis process leads the learners to co-construct a proposed solution (Torp and Sage 2002).

One strength of the PBL framework is that learners are active drivers of the learning process and can develop a deeper understanding of the concepts related to the problem starting from many different levels of prior understanding. PBL is an effective strategy for both novices and advanced learners. PBL is also flexible enough to be useful in nearly any science context.

One challenge for teachers and educational planners, though, is that implementing PBL for the classroom requires advance planning. An effective problem should be authentic, and the challenges presented in the problems need to be both structured and ill-defined to allow genuine and productive exploration by students. Meyer (2010) suggested that these problems help students learn to be "patient problem solvers." For most instructors, getting started with PBL in the science classroom is easiest with existing problems. However, there are very few tested PBL problems available in print or on the internet. Valuable resources exist that describe in general what PBL is, how to develop lessons, and how PBL can help students, but curriculum resources are much harder to find.

In this book, we present a discussion of the PBL structure and its application for the K–12 science classroom. We also share a collection of PBL problems developed as part of the PBL Project for Teachers (PBL Project), a National Science Foundation–funded professional development program that used the PBL framework to help teachers develop a deeper understanding of science concepts in eight different content strands (McConnell et al. 2008; McConnell, Parker, and Eberhardt 2013). Each content strand had a group of participants and facilitators who focused on specific concepts within one of the science disciplines, such as genetics, weather, or forces and motion. The problems presented in this book were developed by content experts who facilitated the workshops and revised the problems over the course of four iterations of the workshops. Through our work to test and revise the problems, we have developed a structure for the written problem that we feel will help educators implement the plans in classrooms.

Because the problems have been tested with teachers, we have published research describing the effectiveness of the problems in influencing teachers' science content knowledge (McConnell, Parker, and Eberhardt 2013). The research revealed that individuals with very little familiarity with science concepts can learn new ideas using the PBL structure and that the same problem can also help experienced science learners with a high degree of prior knowledge refine their understanding and learn to better explain the mechanisms for scientific phenomena.

Alignment With the *Next Generation Science Standards*

To ensure that the problems presented here are useful to science teachers, we have included information aligning the objectives and learning outcomes for each problem with the *NGSS* (NGSS Lead States 2013). The *NGSS* present performance expectations for science education that describe three intertwined dimensions of science learning: science and engineering practices (SEPs), disciplinary core ideas (DCIs), and crosscutting concepts (CCs). The *NGSS* emphasize learning outcomes in which students integrate the SEPs, DCIs, and CCs in a seamless way, resulting in flexible and widely applicable understanding.

The learning targets for the PBL problems included in this book were originally written with attention to the science concepts—what the *NGSS* calls disciplinary core ideas. The aim of the PBL Project was to enhance teachers' knowledge of these core ideas. But implicit in the design of the PBL process is the need for learners to use the practices of science and make connections between concepts that reflect the CCs listed in the standards. PBL problems align well with the *NGSS* because these real-world situations present problems in a similar framework: SEPs, DCIs, and CCs are natural parts of the problems. We describe the alignment of the PBL problems with the *NGSS* in more detail in Chapter 2. As states begin to adopt these standards or adapt them into state standards, Chapter 2 should help teachers and teacher educators fit the problems within their local curricula.

Intended Audiences and Organization of the Book

As mentioned earlier, the PBL problems in this book have been shown to be effective learning tools for learners with differing levels of prior knowledge. Some teachers who participated in the PBL Project used problems from the workshops in their K–12 classrooms, and facilitators with the project have also incorporated problems from this collection into university courses.

Chapter 2 discusses the alignment of the PBL problems and analytical framework with the *NGSS.* Chapter 3 describes strategies for facilitating the PBL lessons. In Chapter 4, we share tips for the classroom teacher on grouping students, managing information, and assessing student learning during the PBL process.

Chapters 5–8 present the problems we have designed and tested. Each chapter includes problems from one content strand (describing motion, forces and motion, engineering energy transformations, or engineering electricity and magnetism), alignment with the *NGSS,* the assessment questions we used to evaluate learning, model responses to the assessments, and resources for the teacher and students that help provide relevant information about the science concept and problem. To help you locate the problems that are most appropriate for your classroom, we have included a catalog of problems (see p. xi); the catalog is in tabular format and will let you scan the list of problems by content topic, keywords and concepts, and grade bands for which the problems were written.

We hope that this collection of problems will serve as a model for educators who want to design and develop problems of their own. For instance, some problems in this book, such as Rescue Force (Chapter 6) and Rube Goldberg Machine (Chapter 7), use materials that may not be available or procedures that may not be possible in some classroom settings. A teacher with a different set of available materials should modify the problems and activity guides to match the context of his or her classroom. In these cases, we encourage teachers to modify and adapt problems to fit contexts familiar to their own students. Chapter 9 discusses features of an effective problem that can help guide the efforts of teachers wishing to create their own PBL lessons.

This book is the third volume in a series. The first volume presented life science problems, and the second volume offered problems specifically written for teaching Earth and space science. This volume features physical science problems. The fourth volume will contain tips and examples for planners of teacher professional development programs. As you modify and implement lessons from these books, you can begin to develop your own problems that meet the needs of your students.

Safe and Ethical Practices in the Science Classroom

With hands-on, process- and inquiry-based laboratory or field activities, the teaching and learning of science today can be both effective and exciting. Successful science teaching needs to address potential safety issues. Throughout this book, safety precautions are described for investigations and need to be adopted and enforced in efforts to provide for a safer learning and teaching experience.

Additional applicable standard operating procedures can be found in the National Science Teacher Association's Safety in the Science Classroom, Laboratory, or Field Sites document (*www.nsta.org/docs/SafetyInTheScienceClassroomLabAndField.pdf*).

Disclaimer: The safety precautions of each activity are based in part on use of the recommended materials and instructions, legal safety standards, and better professional practices. Selection of alternative materials or procedures for these activities may jeopardize the level of safety and therefore is at the user's own risk.

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CATALOG OF PROBLEMS

Problem	Page Number	Keywords and Concepts	Grade Band: Grades K–2	Grades 3–5	Grades 6–8	Grades 9–12
CHAPTER 5: GET MOVING						
1. Get Me Out of Here	70	Distance, direction, motion	•	•	•	
2A. Fastest Beetle	82	Distance, position, speed		•		
2B. Fastest Human	91	Distance, position, instantaneous and average speed or velocity			•	•
3. Constantly Moving	101	Distance, position, time, speed, velocity		•	•	•
4. Good Driver	109	Distance, position, time, speed, velocity, acceleration		•	•	•
CHAPTER 6: FORCES AND MOTION						
1. Asteroid Field	130	Force, acceleration, direction, speed, velocity, Newton's first and second laws of motion	•	•	•	
2. Cartoon Cliff Escape	141	Force, acceleration, velocity, speed, direction, gravity, vertical motion		•	•	
3. Rescue Force	149	Force, acceleration, direction, mass		•	•	
CHAPTER 7: ENGINEERING ENERGY TRANSFORMATIONS						
1. An Energetic Ride	164	Conservation of energy, kinetic energy, potential energy, energy transfers and transformations		•	•	
2. Rube Goldberg Machine	176	Energy conservation, kinetic energy, potential energy		•	•	•
3. Keep It Warm, Keep It Chill	189	Thermal energy, energy transfer, insulation, conduction			•	•
CHAPTER 8: ENGINEERING ELECTRICITY AND MAGNETISM						
1. A Light in the Dark	205	Electrical circuits, batteries, light bulbs, electricity		•	•	•
2. Wiring a Cabin	218	Electrical circuits, electricity, batteries, light bulbs, fuses, switches		•	•	•
3. Cool It	229	Electricity, magnetism, electric current, electric magnet, electric motor, polarity		•	•	•

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DESCRIBING THE PROBLEM-BASED LEARNING PROCESS

As a science teacher, you probably use a variety of approaches and strategies in the classroom. On any given day, you may lecture, lead group discussions, teach an inquiry-based lab, assign projects, ask students to complete individual reading and writing assignments, and perform many other types of tasks. All of these strategies have a legitimate purpose, and we encourage teaching that employs a diverse range of activities.

Why Problem-Based Learning?

In this chapter, we will discuss why problem-based learning (PBL) is one of the many tools you should keep in your teaching toolbox, ready to be used at appropriate times during your teaching. We will also give you some background information about how PBL was developed, how it works in a range of disciplines, and a basic framework for a PBL lesson. In later chapters, we will provide further detail on the "nuts and bolts" of teaching a PBL lesson and how to develop and facilitate learning activities using this strategy. The advice we will offer and the science problems we will share in later chapters come from our own experiences in using PBL to teach concepts to teachers. Many of the lessons have also been used with students across a wide range of age groups.

We have used these lessons because of a driving philosophy that it is imperative to help students develop the ability to inquire, solve problems, and think critically and independently (Barell 2010). Many of the thinking skills directly taught in the PBL process are included in the goals of 21st-century skills (Barell 2010; Ravitz et al. 2012). PBL is well suited to achieving the goal of developing thinking skills because it presents learners with authentic stories that require application of scientific concepts to construct and evaluate possible actions. In the process of solving problems, students plan, gather, and synthesize information from multiple sources or findings from investigations, evaluate the credibility of their sources, and communicate their ideas as they justify their claims. Students are guided by a set of simple prompts that help them organize information and generate questions and hypotheses.

In our experience, learners quickly adopt this framework as a habit of mind, and they begin to apply this critical-thinking strategy to other problems and real-world situations. The framework becomes a habit because the process is easily internalized and uses simple language. Asking the question "What do we know?" is easy for most students to remember and use, and the rest of the framework is just as direct and intuitive. This process also resembles KWL (McAllister 1994), a formative assessment strategy used widely in elementary classrooms. In KWL, students are asked to verbalize and record a list of what they "Know," what they "Want" to know, and what they have "Learned." The feature added by the PBL framework that makes it so "scientific" is the inclusion of hypotheses, leading students to make predictions and justify them.

Teachers in the professional development program for which these problems were developed quickly adopted the language and turned "PBL" into a verb. When they encountered new problems, they initiated the process with phrases like "Let's PBL this." K–12 students are just as quick to adopt the cognitive framework. This is one benefit of using PBL in your teaching.

Historical Background of PBL as a Process

PBL's origins are rooted in this same desire to help learners solve real-world problems. PBL was originally developed as a strategy for developing content knowledge in the context of assessing and diagnosing patients (Barrows 1980). Medical students had been successful in memorizing information, but when asked to use the information to diagnose a patient, they were unable to apply their knowledge. What was lacking in their understanding was how the ideas they had memorized were useful in diagnosing and treating patients in an authentic "problem" they would encounter as doctors. The challenge to medical school faculty was finding a way to teach students to think like doctors, not like students preparing for a test. PBL presents opportunities in just such a contextualized manner, so medical schools began using this strategy. PBL was shown to be effective in helping medical students both learn anatomy, pathology, and medical procedures and apply this knowledge to medical cases. Thus, PBL became widespread in medical schools.

The same issues seen in the field of medical education are important concerns for science students, too. Just as second-year medical students struggle to transfer what they learn into practice, science students struggle to understand how measuring or describing velocity and acceleration can be applied to real-world issues, or why energy transformations are important to the world in which they live. Bransford and Schwartz (1999) suggested that transfer of knowledge is enhanced if the concepts are shown in a variety of contexts, rather than always presenting them in the same or very similar contexts. They also recommended using metacognition to support the transfer of knowledge across contexts. One strength of PBL is that the framework we will present is a metacognitive structure—students are expected to be aware of what they know and what they need to know to solve the problem.

Bringing PBL to Other Disciplines

Since its beginnings in medical education, PBL has been adapted to business, law, law enforcement, and other subjects (Hung, Jonassen, and Liu 2008) and has been modified for science teaching (Allen et al. 2003; Gordon et al. 2001). Research by Hmelo-Silver (2004) suggested that PBL leads to increased intrinsic motivation of learners to become more self-directed. Another study reported that teachers who use PBL in their classroom teach more 21st-century skills (Ravitz et al. 2012).

In this book, the model presented for using PBL to teach science content has similar features to the PBL activities from other subjects, but it has been refined through research-based evaluation of the process when used for teaching science content in the PBL Project for Teachers (McConnell et al. 2008), as described in the next section.

The PBL Project for Teachers

The context in which the materials presented in this book were created was the PBL Project for Teachers, a National Science Foundation–funded teacher professional development program (McConnell et al. 2008).[1] The PBL Project for Teachers was designed to accomplish several goals, including deepening K–12 teachers' scientific understanding, developing inquiry-based science lesson plans, and facilitating a form of reflective practice that applied the same PBL principles to the study of teaching.

In this program, K–12 teachers spent three days of a two-week institute learning science content surrounding standards they had identified as areas of need in their curricula. Facilitators for each of eight content strands planned PBL lessons to address those specific standards. These facilitators were experts in their respective science content areas who worked in teams of at least three. The teams wrote PBL problems that addressed the science standards teachers identified. Then, the teams shared these problems with peers for review. The problems were then tested and revised in an iterative fashion over four cohorts of teachers. The final versions were the basis for the problems found in this book and in future volumes in the PBL series.

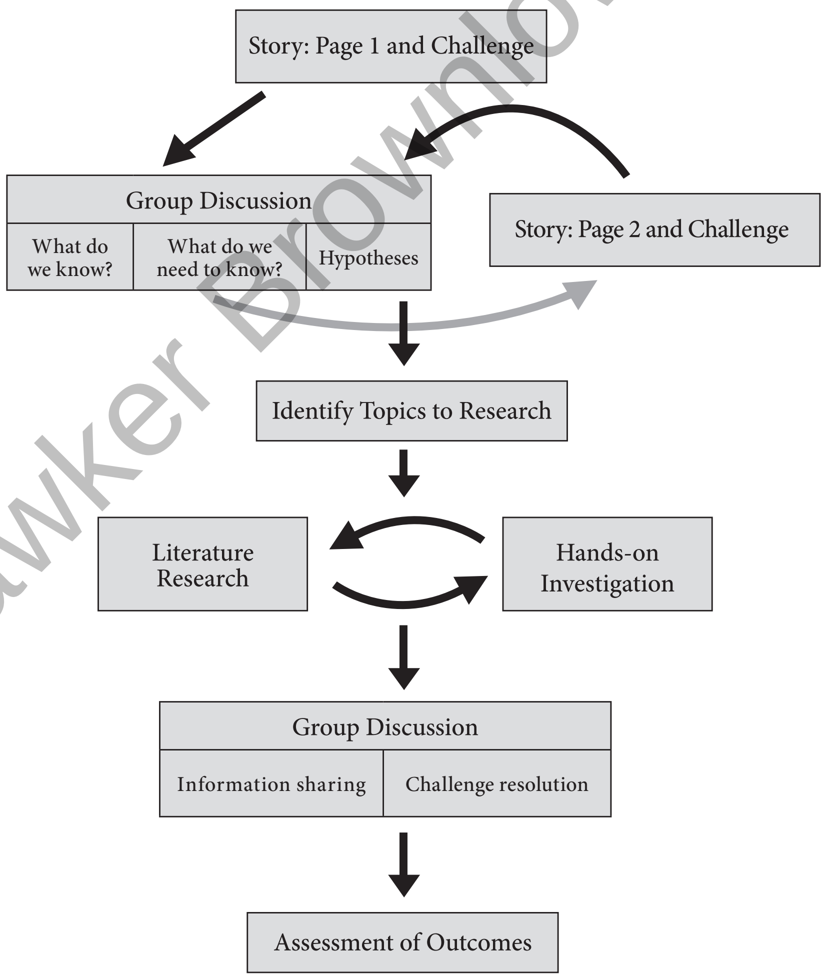
The activities were modified for use in the K–12 classroom, with a focus on problems for life science, Earth and space science, and physics. These modifications included changing the context of the story to relate more to students in specific grade bands and changing the reading level to match the target audience. The concepts addressed in the problems remained consistent, in part because pre-assessments with teachers revealed very similar prior understandings as K–12 students, especially for teachers who were not science majors. Research to assess content learning showed that most of the teachers gained a deeper understanding of their chosen content as a result of the PBL lessons (McConnell, Parker, and Eberhardt 2013). Participants then used the content knowledge they gained to develop inquiry-based lesson plans and used PBL to analyze problems in teaching practice. During this stage, many of the problems were tested in K–12 and college courses, with revisions to address any difficulties encountered.

[1] National Science Foundation special project number ESI-03533406, as part of the Teacher Professional Continuum program.

The PBL Framework

In this book, we use the same framework for designing and facilitating the PBL lessons that we used during the PBL Project for Teachers. This framework draws from the guidelines described by Torp and Sage (2002) and the model used by the Michigan State University College of Human Medicine (Christopher Reznich, personal communication, October 11, 2004). In this model, students are presented with a problem, usually in the form of a story divided into two parts (Christopher Reznich, personal communication, October 11, 2004). There can be more than two parts to the story, but the key feature is that information is presented to students in stages. Figure 1.1 shows a representation of the PBL process.

Figure 1.1. The PBL Process



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